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Review article

The comparative effect of exercise interventions on balance in perimenopausal and early postmenopausal women: A systematic review and network meta-analysis of randomised, controlled trials

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ABSTRACT

In addition to a range of physiological and psychological symptoms, menopause causes a decrement to balance performance and risk of falls. This review aimed to determine the effects of exercise interventions on balance in perimenopausal and early postmenopausal women. Web of Science, PubMed, CINAHL, SPORTDiscus and Cochrane Central Register of Controlled Trials databases were searched. Randomised, controlled trials of exercise interventions in perimenopausal or early postmenopausal populations with an average age of 65 years or younger reporting balance measures were included. Risk of bias was assessed using Cochrane RoB 2. A random effects model network meta-analysis was performed to assess the effect of exercise on balance. Standardised mean differences with 95 % confidence intervals were used as the measure of effect. Twenty-six studies were included after screening. Network meta-analyses were conducted for 5 balance variables. Whole-body vibration (standardised mean difference: 2.25, confidence interval: 0.08; 4.43), balance (standardised mean difference: 1.84, confidence interval: 0.15; 3.53), balance + nutrition (standardised mean difference: 3.81, confidence interval: 1.57; 6.05) and resistance (standardised mean difference: 1.43, confidence interval: 0.41; 2.46) exercise improved Berg balance scale performance. Resistance + aerobic + balance exercise improved one-leg stance (standardised mean difference: 0.80, confidence interval: 0.39; 1.22) and whole-body vibration improved anterior-posterior (standardised mean difference: −0.89, confidence interval: −1.48; −0.31), medio-lateral (standardised mean difference: −0.58, confidence interval: −1.15; −0.01) postural sway and falls indices (standardised mean difference: −0.75, confidence interval: −1.45; −0.04). Exercise improved all balance measures and should be considered as an adjunct therapy in perimenopausal and postmenopausal women. Whole-body vibration was most frequently the highest ranked intervention; resistance and balance training also improved balance.

1. Introduction

Menopause is associated with a range of physiological, psychological and social implications [1,2]. Changes in endocrine function have also been related to higher risks for cardiovascular disease, stroke and osteoporosis [3–5]. Furthermore, an earlier age of menopause onset is related to greater frailty in later life [6].

Postmenopausal women demonstrate worse global physical function, strength and walking speed, irrespective of age, than premenopausal women [7,8]. Declining oestrogen concentration onset during perimenopause have been implicated in a decline in muscle mass and function [9]. Lower muscle function impairs balance in older adults, which increases the risk of falls [10]. Falls are a major concern in postmenopausal women [11], postmenopausal osteoporosis increases the fracture risk from falls as oestrogen deficiency increases bone turnover [3]. Additionally, falls have a bidirectional association with depression and anxiety, with falls increasing likelihood of depressive symptoms and experiencing depression in turn increasing the risk of falls [12]. This relationship is exacerbated in women as perimenopause and postmenopausal women are at higher risk of developing depression and anxiety symptoms [13]. Exercise and physical activity have been found to be associated with improved mental health outcomes [1,14]. Combined, these findings highlight the importance of physical function and balance in this population.

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Static and dynamic balance predict falls risk in older adults [15,16] and are better prospective predictors of fractures in osteoporotic menopausal and postmenopausal women than bone mineral density (BMD) [17]. Furthermore, clinical balance assessments can predict BMD in menopausal women with and without osteoporosis [18]. Balance performance, therefore, represents a key component of physical health in perimenopausal and postmenopausal women.

A wide range of exercise strategies including resistance [19], balance [20] and whole-body vibration (WBV) [21] have been employed to improve balance in menopausal and postmenopausal women. Recent systematic reviews have considered the effects of individual types of exercise, such as Pilates [22] or WBV training [23], on balance and falls risk of postmenopausal women. However, there has been no comprehensive review of the effects of different exercise types on measures of balance in perimenopausal, menopausal and postmenopausal women.

The aim of this systematic review and network meta-analysis was to determine the effect of exercise interventions on balance of perimenopausal and early postmenopausal women in randomised, controlled trials and to determine the ranking of relative effect of the different intervention types.

2. Method

The protocol for this review has been registered on the PROSPERO register of systematic reviews (registration number: CRD42022338701). The review was conducted and reported according to the PRISMA guidelines for network meta-analyses [24]. The PRISMA checklist for network meta-analyses is provided in the supplementary material.

2.1. Search strategy and selection criteria

A systematic search for randomised, controlled trials was performed in the Web of Science, PubMed, CINAHL, SPORTDiscus and Cochrane Central Register of Controlled Trials databases. The final search was completed on 9th December 2022. Each database was searched using the following primary search string: (Menopaus* OR perimenopaus* OR postmenopaus*) AND (balance OR stability OR postur*) AND (exercise OR training OR intervention) AND (RCT or "randomized controlled trial" OR "randomised controlled trial"). The same primary search string was used in each database. In the PubMed, CINAHL and Cochrane Central Register of Controlled Trials databases the MeSH terms AND "menopause" AND "balance, postural" were used. The reference lists of included studies were also searched.

Inclusion criteria consisted of 1) female participants specifically characterised as menopausal, perimenopausal or postmenopausal, with an average sample age no older than 65 years to avoid significant age-related effects, 2) an exercise intervention of any mode, 3) includes measure(s) of standing balance or postural control, 3) randomised, controlled design, 4) written in English, 5) peer reviewed article and 6) original research. Exclusion criteria included 1) a non-perimenopausal or non-postmenopausal population, 2) average sample age over 65 years, 3) animal models of menopause, 4) no measure of standing balance or postural control, 5) not a randomised, controlled design, 6) literature reviews, conference proceedings, study protocols or position statements and 7) not written in English.

The title and abstract of returned records were screened independently by two reviewers. The full text of included studies after the first stage were then screened independently by two reviewers. At each screening stage, disagreements were resolved by the third reviewer.

2.2. Data extraction

Data extracted for participant samples included the number, age, height, body mass, menopause status, reported comorbidities and use of additional hormone or dietary supplementation. Data extracted for the intervention protocols included the exercise mode, and duration of the intervention. The balance outcome measure(s) used were also extracted along with the pre and post intervention mean and standard deviation, percentage change or odds ratios. For studies where the desired data were not reported, or where outcome data was only reported graphically, authors were contacted to request the data.

2.3. Risk of bias assessment

The risk of bias for included studies was assessed using Cochrane RoB 2: A revised Cochrane risk-of-bias tool for randomised trials [25]. Risk of bias assessment was completed by a single reviewer and checked by a second reviewer. Disagreements were resolved by a third reviewer.

2.4. Data analysis

A frequentist, random effects network meta-analysis (NMA) was performed to determine the comparative effect of exercise interventions on balance measures. NMA allows for the comparison of the effects of multiple intervention types on an outcome by assessing both direct and indirect evidence, derived from common comparators [26]. Non-exercise control groups were used as the comparison condition. A separate NMA was performed for each balance measure reported by at least 3 studies. NMA were conducted in R (version 4.2.1, R Core Team) using the *netmeta* package (version 2.5–0, http://cran.at.r-project.org/web/packages/netmeta/). Analogous balance measures were pooled into a single NMA. Exercise interventions were grouped based on their primary component, for example, if a resistance programme used walking or coordination exercises as part of a warm-up this would be classified as a resistance programme. Where interventions were assigned a combined classification, *e.g.*, resistance plus balance, these were considered to have relatively similar priority in the intervention, with similar duration, volume or intensity for the different components. Intervention groups that included exercise and a dietary, medicinal or hormonal supplementation were also included. If all intervention groups were given the same supplementation, then the interventions were categorised only by the exercise intervention type.

Effect sizes were calculated as standardised mean differences and their 95 % confidence intervals (CI). The structure of the network was determined by a network graph, where the size of the nodes is proportional to the number of participants receiving that intervention and the thickness of the edges is proportional to the number of studies for that comparison. Exercise interventions were ranked according to P-score, the mean probability that a treatment with a larger P-score is more effective than treatments with lower P-scores [27]. Treatment comparisons were performed using a z-test. The significance value was set at $p < 0.05$. The purpose of this review was to determine the effects of exercise on balance rather than comparing specific types of exercise. Therefore, when reporting the results, only results of exercise *vs* control conditions are reported and included in the estimations of treatment rank, rather than pairwise comparisons of all exercise types.

Heterogeneity is commonly reported in meta-analysis using the I^2 measure of heterogeneity; however, since this can be influenced by participant numbers, and there was a large variation in participant numbers for different exercise conditions, the τ^2 statistics was used to represent global heterogeneity in the network. τ^2 values of approximately 0.04, 0.16 and 0.36 were considered to represent low, moderate and substantial heterogeneity, respectively [28]. Additionally, a design-by-treatment analysis of the Cochran's Q statistic was used to determine within-designs heterogeneity (Q_H) and between-designs inconsistency (Q_I). Inconsistency in NMA arises when there is discrepancy between the determined effects of a treatment condition by direct and indirect evidence. Where significant global heterogeneity was present, a sensitivity analysis was performed by removing the designs that caused the most heterogeneity and repeating the NMA.

3. Results

3.1. Search results

A total of 978 articles were identified and screened against the inclusion criteria. Twenty-six RCT's were included in the review with a total of 1560 participants. Of the 26 included studies, 19 were included in the quantitative NMA. The progression of studies through the review is depicted in Fig. 1.

3.2. Risk of bias assessment

The majority of included studies had some concerns for risk of bias (88.5 %), with a high risk of bias present in 3.8 % of studies and low risk of bias in 7.7 % of studies (Fig. 2). Domains 2, "deviations from intended interventions", and 5, "selection of the reported result", accounted for most concerns. In domain 2 the concern generally arose from a lack of blinding of participants, this is inherent and unavoidable in most exercise interventions, however, in many studies it was also not reported whether those collecting data were blinded or not. In domain 5 the concerns arose from a lack of published or registered analysis protocol that the published trial could be compared against.

3.3. Study characteristics

All study characteristics are presented in Table 1. The average age of studied populations ranged from 47 to 65 years. Of the 26 studies included 23 included early postmenopausal women only, 2 included perimenopausal women only and 1 included perimenopausal and postmenopausal women. Osteoporotic populations were included in 9 studies and participants with vitamin D deficiency were included in 1 study, no other studies reported participants with comorbidities. Additionally, 11 studies reported the inclusion of a hormonal or nutritional supplementation in one or more of the study groups.

The most adopted exercise intervention types were resistance, aerobic and balance training. Eight studies had at least 1 resistance training group and there were a further 13 intervention groups comprised of a combination of resistance training and another form of exercise. Aerobic exercise was included either as the sole intervention or in combination with another exercise type in 10 studies. Balance exercise was included either as the sole intervention or in combination with another exercise type in 11 studies. Intervention duration ranged from 6 weeks to 18 months and frequency ranged from 2 to 15 sessions per week.

The Berg Balance Scale (BBS) was reported by 10 studies as the most frequently utilised measure of balance, followed by one leg stance time (OLS), reported by 9 studies. Three studies reported measures of centre of pressure postural sway and 3 studies reported a stability or falls index, comprised of multiple sway measures. Three studies reported variations

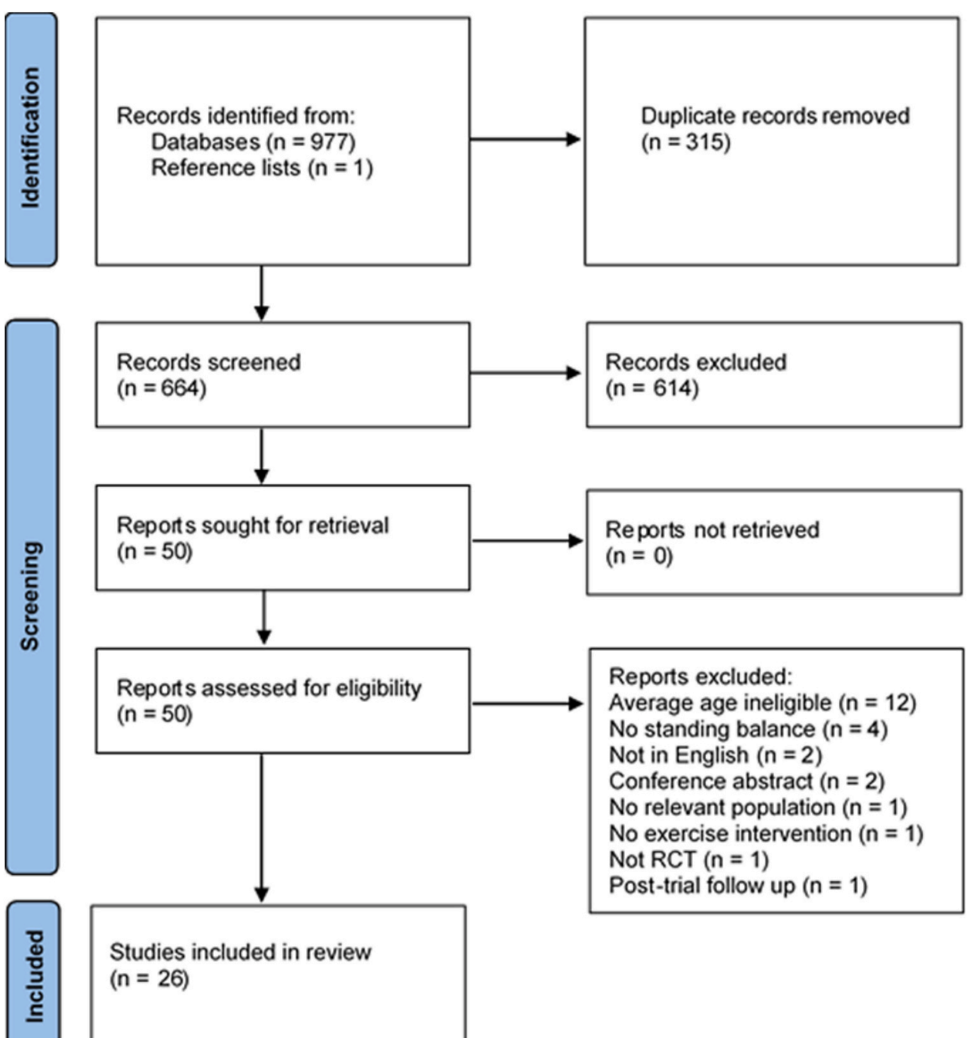

Fig. 1. Flow chart of studies through the review.

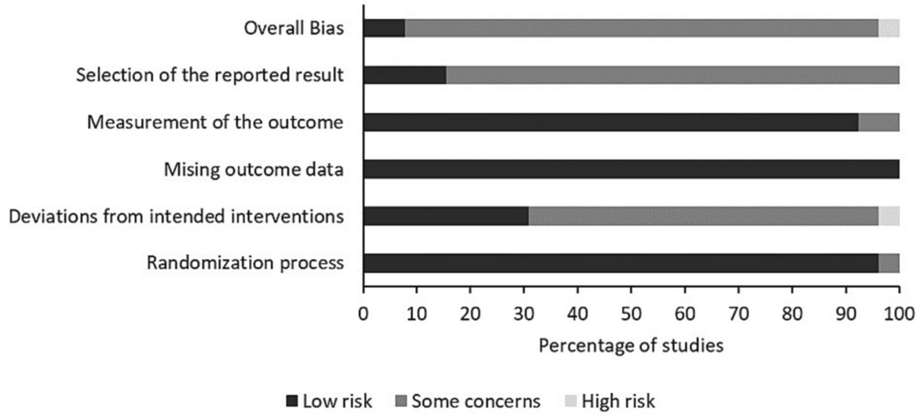

Fig. 2. Summary of the percentage of studies with low risk, some concerns and high risk of bias for each domain of the Cochrane RoB 2 tool.

of OLS outcomes and 2 studies reported outcomes derived during tandem stance.

3.4. Network meta-analysis

3.4.1. Berg balance scale

The network geometry for the studies that reported the use of BBS [19–21,29,34,38,39,41,46,50] is shown in Supplementary Fig. 1. Balance + nutritional supplementation ($z = 3.34$, $p = 0.001$), WBV ($z = 2.03$, $p = 0.042$), balance ($z = 2.13$, $p = 0.033$) and resistance ($z = 2.74$, $p = 0.006$) training significantly improved BBS scores compared with control. However, there was no significant effect for any other intervention type (Fig. 3A). Treatment ranking found balance + nutritional supplementation to be the most effective intervention, followed by WBV, balance and resistance training (Fig. 3A). However, there was no direct evidence for the comparison of balance + nutritional supplementation or WBV to control.

There was substantial global heterogeneity, although non-significant within-designs heterogeneity ($\tau^2 = 0.39$, $Q_H = 2.58$, $p = 0.108$), and significant inconsistency ($Q_I = 6.70$, $p = 0.010$) in the network. Design based decomposition showed that control *vs.* resistance + balance *vs.* resistance + balance + nutrition design ($Q = 4.42$) and the control *vs.* resistance + balance design ($Q = 2.27$) had the largest contribution to the Q_H. When studies with these designs [19,41] were removed and the NMA was repeated WBV, resistance and balance remained the only significant interventions, with the same treatment ranking and moderate heterogeneity ($\tau^2 = 0.27$).

3.4.2. One leg standing

The network geometry for the studies that reported the use of OLS [33,35,36,42,45,47] is shown in Supplementary Fig. 2. Three studies had to be excluded from the NMA for OLS to ensure a connected network [38,46,51]. Only resistance + aerobic + balance training significantly ($z = 3.77$, $p < 0.001$) improved OLS scores compared with control (Fig. 3B). Treatment ranking found resistance + aerobic + balance training to be the most effective intervention (Fig. 3B). There was low global heterogeneity and non-significant within-designs heterogeneity ($\tau^2 = 0.07$, $Q_H = 4.58$, $p = 0.101$) and no inconsistency ($Q_I = 0$).

3.4.3. Postural sway

Postural sway was analysed separately in the anterior-posterior (AP) [20,32,49] and medio-lateral (ML) directions [20,32,49], network geometries are shown in Supplementary Figs. 3 and 4 respectively. For AP postural sway only WBV had a significant effect ($z = -2.98$, $p = 0.003$), WBV also had the highest treatment ranking followed by balance training (Fig. 3C). There was low global heterogeneity, within-designs heterogeneity ($\tau^2 < 0.01$, $Q_H < 0.01$, $p > 0.050$) and low inconsistency ($Q_I < 0.01$, $p > 0.050$) for AP postural sway.

For ML postural sway only WBV had a significant effect ($z = -2.00$, $p = 0.046$), however, balance and aerobic training were the highest ranked treatments followed by WBV (Fig. 3D). There was low global heterogeneity, within-designs heterogeneity ($\tau^2 < 0.01$, $Q_H < 0.01$, $p > 0.050$) and low inconsistency ($Q_I < 0.01$, $p > 0.050$) for ML postural sway.

3.4.4. Stability indices

Network geometry for studies that reported the use of a composite stability or falls index based on postural sway [41,44,48] is shown in Supplementary Fig. 5. Only WBV had a significant effect on stability and falls indices ($z = -2.08$, $p = 0.037$), WBV also had the highest treatment rank followed by resistance + high impact training (Fig. 3E). There was low global heterogeneity, within-designs heterogeneity ($\tau^2 < 0.01$, $Q_H < 0.01$, $p > 0.050$) and low inconsistency ($Q_I < 0.01$, $p > 0.050$) for stability and falls indices.

3.5. Qualitative synthesis

Six studies reported balance variables that were not reported by any other study and were therefore not included in the NMA. The time that tandem stance could be maintained was increased by aerobic training [43] and resistance + aerobic + balance training decreased postural sway velocity in tandem and OLS [36]. The short physical performance battery balance score was also improved by resistance training [40]. Resistance + aerobic exercise increased the percentage of participants that achieved 60 s of OLS [30] but had no effect on velocity of voluntary postural shifts to targets in perimenopausal women [31]. Finally, resistance but not WBV training improved the Gleichgewichtstest balance test performance [37].

4. Discussion

The present systematic review examined the effects of exercise interventions in comparison to non-exercise controls on balance of perimenopausal and postmenopausal women using direct and indirect evidence synthesised by NMA. The BBS was the most reported balance measure and was improved by WBV, resistance, balance and balance + nutrition training. However, AP and ML postural sway, and stability and falls indices were only improved by WBV. This review also highlighted the breadth in intervention approaches in this population. Risk of bias assessment in this review highlighted the need for more robust conduct of RCTs in this area. Most studies reported some concerns for overall risks of bias because of a lack of blinding in the experimental design or a lack of preregistration or publication of the trial protocol. However, it should be noted that very few studies demonstrated high risks of bias in domains related to the design, reporting and conduct of the trials.

For the BBS, AP postural sway, ML postural sway, and stability and

Table 1
Characteristics of included studies.

Reference	Intervention groups	N per group (N analysed)	Co-morbidities	Mean age, years (SD)	Menopause status	Intervention tasks	Intervention duration	Intervention frequency, session/week	Balance outcomes
Almeida et al. [29]	RES	17(11)	–	56.2 (5.5)	Postmenopause	RES: whole body machine exercises at 75 % 1RM	8 weeks	2	BBS
	RES + PBM	17(13)	–	58.1 (6.1)					
Asikainen et al. [30]	CON	45(44)	–	56.5 (4.2)	Postmenopause	RES: whole body weight or dumbbell exercises + AER: walking at 65 % VO_{2max} for 300 kcal	15 weeks	5	OLS (% achieving 60s)
	RES + AER	46(46)	–	57.8 (4.4)					
	RES + AER (fractioned)	43(43)	–	57.6 (4.2)					
Bergstrom et al. [31]	CON	20(12)	–	47.0 (3)	Perimenopause	RES: unspecified whole body resistance exercises + AER: walking 30 min	18 months	5	COP shift to target
	RES + AER	20(11)	–	47.0 (2)					
Bolton et al. [32]	CON	20(18)	Osteoporosis	56.3 (4.7)	Postmenopause	RES: body weight and machine exercises at 8RM	12 months	3	COP postural sway
	RES	19(19)	Osteoporosis	60.3 (5.6)					
Cao et al. [33]	CON	47(38)	–	65.0 (5.1)	Postmenopause	300 kcal per session total RES: body weight resistance + AER: walking	12 months	4	OLS time
	RES + AER	49(48)	–	63.9 (5.0)					
	RES + AER + Calcium	41(40	–	63.5 (4.4)					
Dizdar et al. [20]	BAL	27(25)	Osteoporosis	57.9 (4.5)	Postmenopause	BAL: 13 single and double leg exercises 10–15 reps RES: whole body resistance exercises with sandbags at 50 % 10RM AER: walking 30 mins at 50–75 % max HR	12 weeks	3	BBS, COP postural sway
	RES	28(25)	Osteoporosis	59.9 (5.5)					
	AER	27(25)	Osteoporosis	60.9 (6.5)					
El Mohsen et al. [34]	CON	12(12)	Osteoporosis	58.6 (4.0)	Postmenopause	RES: lower body body weight resistance exercises + BAL: 7 exercises 1 min per task	6 weeks	5	BBS
	RES + BAL	12(12)	Osteoporosis	59.8 (4.1)					
Filipovic et al. [35]	CON	51(49)	Osteoporosis	64.2 (5.1)	Postmenopause	RES: whole body body weight and banded self-determined intensity at "difficult" + AER: walking 60 mins at 70 % max HR + BAL: 12 movements 3 sets 12–15 reps	12 weeks	5	OLS time
	RES + AER + BAL	52(47)	Osteoporosis	64.4 (5.5)					
Fu et al. [36]	CON	24(24)	–	51.3 (5.4)	Postmenopause + Perimenopause	7 stations 5 min per station total RES: Whole body body weight resistance + AER: walking + BAL: challenged balance	12 weeks	2	OLS and Tandem COP sway velocity
	RES + AER + BAL	26(26)	–	52.2 (5.6)					
Kienberger et al. [37]	CON	25(21)	Osteoporosis	58.7 (8.2)	Postmenopause	WBV: squat holds 18 Hz at 2 mm amplitude RES: whole body machine exercises at 50–70 % 1RM	12 months	2	Gleichgewichtstest balance test
	WBV	18(18)	Osteoporosis	56.1 (5.1)					
	RES	22(22)	Osteoporosis	62.8 (6.8)					
Li et al. [38][a]	BAL	18(18)	Osteoporosis	57.0 (1.6)	Postmenopause	BAL: Baduanjin exercises 45 mins individualised intensity	16 weeks	5	BBS, OLS time
	BAL + EXD	17(17)	Osteoporosis	57.3 (1.5)					
Murtezani et al. [39]	RES + AER	33(31)	Osteoporosis	60.7 (7.6)	Postmenopause	RES: back extension resistance 70–80 % 1RM + AER: Loaded walking and stair climbing vest 10 % body mass Aquatic: weighted	10 months	3	BBS
	Aquatic RES	31(30)	Osteoporosis	59.8 (6.0)					

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Table 1 (*continued*)

Reference	Intervention groups	N per group (N analysed)	Co-morbidities	Mean age, years (SD)	Menopause status	Intervention tasks	Intervention duration	Intervention frequency, session/week	Balance outcomes
						upper and lower body movements			
Nahas et al. [40]	RES	25(11)	–	62.0 (2.6)	Postmenopause	RES: whole body machine and free weight at 8-12RM	10 weeks	3	SPPB balance component
	RES + Protein	22(12)	–	64.7 (2.8)					
Ozsoy-Unubol et al. [41][a]	CON + Vitamin D	22(21)	Vitamin D deficient	55.8 (5.1)	Postmenopause	RES: body weight core resistance + BAL: 8 balance movements	8 weeks	3	BBS, Biodex stability index
	RES + BAL	21(18)	Vitamin D deficient	55.1 (5.5)					
	RES + BAL + Vitamin D	22(20)	Vitamin D deficient	55.7 (4.8)					
Pano-Rodriguez et al. [42]	RES	17(16)	–	59.7 (3.8)	Postmenopause	RES: squat, deadlift, bench press at 40 % 1RM	10 weeks	2	OLS time
	RES + EMS	17(16)	–	63.1 (3.4)					
Roghani et al. [43]	CON	12(10)	Osteoporosis	45–65	Postmenopause	AER: 20 min walking 50–60 % HR reserve AER + vest: 20 min walking 50–60 % HR reserve with 4–10 % body mass vest	6 weeks	3	Tandem stance time
	AER	12(8)	Osteoporosis	45–65					
	AER + weighted vest	12(9)	Osteoporosis	45–65					
Sen et al. [44]	CON	20(18)	–	54.5 (6.0)	Postmenopause	RES: whole body resistance + IMP: 10–60 double leg jumps WBV: 30-40 Hz at 2-4 mm amplitude lower body isometric holds of 30–300 s	6 months	3	COP frequency falls index
	RES + IMP	19(16)	–	53.1 (4.4)					
	WBV	19(15)	–	55.0 (4.6)					
Shabir et al. [45]	AER + BAL	22(20)	–	45–65	Postmenopause	AER: 15 min 50–60 % max HR walking + BAL: balance ball exercises RES: body weight core resistance + balance on unstable surfaces	6 weeks	3	OLS time
	RES + AER + BAL	22(20)	–	45–65					
Solak et al. [46]	BAL	24(24)	–	55.6 (4.8)	Postmenopause	BAL: 5 lower body balance and hold exercises COORD: 15 whole body Frenkel coordination exercises	4 weeks	5	OLS time, BBS
	COORD	24(24)	–	58.7 (7.1)					
Sucuoglu et al. [21]	WBV	29(21)	–	56.0 (4.2)	Postmenopause	WBV: 30-40 Hz lower body isometric holds + BAL: 8 movements	4 weeks	10–15	BBS
	BAL	26(21)	–	58.8 (5.8)					
Teixeira et al. [19]	CON	50(42)	Osteoporosis	62.8 (4.9)	Postmenopause	RES: 80 % 1RM knee extension + BAL: progressively increasing difficulty movements	18 weeks	2	BBS
	RES + BAL	50(43)	Osteoporosis	63.1 (4.5)					
Teoman et al. [47]	CON	40(40)	–	51.0 (4.2)	Postmenopause	total session Borg RPE 13–14 RES: whole body band and free-weight resistance + AER: 15 min cycle and 6 min aerobic step ups + BAL: trampoline movements	6 weeks	3	OLS time
	RES + AER + BAL	41(41)	–	51.0 (4.0)					
Uusi-Rasi et al. [48][a]	CON	41(39)	–	53.2 (2.1)	Postmenopause	PLYO: multi-directional jumping 10–25 cm obstacles	12 months	3	Biodex stability index
	PLYO + alendronate	41(38)	–	53.0 (2.8)					
	PLYO + placebo	41(37)	–	53.3 (2.2)					
Verschueren et al. [49]	CON	24(24)	–	64.2 (3.1)	Postmenopause	WBV: 35–40 Hz at 1.7–2.5 mm amplitude squat and lunge exercises	6 months	3	COP postural sway
	WBV	25(25)	–	64.6 (3.3)					

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Table 1 (*continued*)

Reference	Intervention groups	N per group (N analysed)	Co-morbidities	Mean age, years (SD)	Menopause status	Intervention tasks	Intervention duration	Intervention frequency, session/week	Balance outcomes
	RES	22(22)	–	63.9 (3.8)		RES: knee extension and leg press 8-20RM			
Xiao et al. [50]	CON	25(25)	–	63.5 (3.7) – both groups	Perimenopause	RES: whole body banded resistance at 6RM	6 months	3	BBS
	RES	25(25)	–						
Young et al. [51]	Dance	15(10)	–	61.9 (7.0)	Postmenopause	Dance: line dance class + RES: squatting with handheld loads + IMP: barefoot stamping 4× per foot	12 months	1–11	OLS time
	Dance + RES	15(9)	–	61.5 (5.2)					
	Dance + RES + IMP	15(12)	–	64.4 (8.0)					

AER: aerobic, BAL: balance, BBS: Berg balance scale, CON: non-exercise control, COORD: coordination, COP: centre of pressure, EMS: electromyostimulation, EXD: Er Xian Decoction, IMP: high impact, OLS: one leg stance, PBM: photobiomodulation, PLYO: plyometric, RES: resistance, RM: repetition maximum, SD: standard deviation, SPPB: short physical performance battery, WBV: whole-body vibration.
+ indicates a multi-component intervention.
[a] Indicates study included a non-exercise based or non-randomised intervention group that was excluded from this analysis.

falls indices WBV exercise improved balance. WBV was also the top ranked intervention for AP postural sway and stability and falls indices and ranked second for BBS. WBV training often combines resistance exercise with a vibration stimulus [21,49]. The benefits of WBV on balance found in this study are likely the result of the additional muscle activity during vibration exposure and the stimulation of muscle spindles and alpha motor neurons leading to strength and neuromuscular adaptions [52]. It should be noted that while the findings of this review indicate the benefits of WBV on balance, which are in agreement with a previous systematic review [23], the NMA results are derived from just 3 studies and a combined 65 participants receiving WBV [21,44,49]. It is possible these findings are the result of small study effects; unfortunately, it was not possible to assess objectively small study effects in this NMA.

Resistance and balance training also improved BBS performance; however, these effects were not seen in postural sway measures where resistance training was the lowest ranked treatment. This finding contrasts with a previous review on the effects of exercise on postural sway [53]. Similarly, balance specific training improved BBS but not postural sway performance. A possible interpretation for these results is that measures of postural sway, which are indicative of postural control mechanisms, may be less sensitive to change in the relatively younger populations studied in this review than the BBS, which is comprised of a range of functional standing tasks that may have greater strength demands. Interestingly, multi-component exercise interventions only significantly improved OLS and in that network only 1 (resistance + aerobic + balance) of the 5 multi-component designs had a significant effect on balance. It is possible that with multi-component interventions, to maintain a reasonable exercise load, each element of the intervention is delivered in a dosage that is lower than the effective dose for that intervention type.

Women undergoing menopause are susceptible to anthropometric, neuromuscular, somatic, and psychological symptoms including an increase in intra-abdominal fat and body mass, reduced muscle mass and strength, and reports of depression and anxiety [54–56] all of which are factors that can impair balance control [10,54,57]. Exercise and physical activity have been shown to have beneficial effects on muscle function, anthropometric, somatic, and psychological menopause symptoms [1,20,45,58]. This suggests that the balance improvements resulting from exercise reported in this review are the result of the complex interaction of neuromuscular, somatic, and psychological factors, which reflects the complex nature of balance control relying on cognitive, sensory and neuromuscular function. Interestingly, whilst a common intervention type, aerobic training did not lead to significant improvements in balance performance as a single component intervention. The low impact aerobic activity adopted in these studies, most commonly walking, may have caused smaller neuromuscular adaptations when compared to WBV or resistance training [59], which could explain the smaller effect in on balance performance evident in the current review.

The broad approach we adopted to the assignment of intervention types to specific treatment categories in the NMA may have influenced the quantitative findings. For example, in the BBS NMA, the resistance exercise category included studies with 8 weeks machine based [29], 6 months elastic band based [50] and 12 weeks sandbag loaded free weight based [20] exercise programmes. This broad approach can increase heterogeneity in the NMA and potentially limit the assumption of transitivity in the network. However, it has been suggested that this broad approach is beneficial in meta-analyses as it increases the generalisability of the findings and increases the power of the quantitative analysis reducing the risk of erroneous conclusions [60]. Despite the broad approach adopted in this review, only the BBS NMA demonstrated significant global heterogeneity resulting from two designs. This global heterogeneity was reduced to moderate following sensitivity analysis. Similarly, significant network inconsistency, disagreement between direct and indirect evidence, which can result from violating the assumption of transitivity, was low in all NMA apart from the BBS NMA, where it was removed following sensitivity analysis. Despite the broad approach adopted, which allowed for the development of a reasonable number of treatment categories, it should also be noted that for each NMA conducted in this review the results represent mostly mixed or indirect evidence [61]. Whilst several studies for each variable made comparisons between an exercise group and a non-exercise control group, this was not the case for many, which should be considered when interpreting the findings of the present review. For example, whilst WBV was the highest ranked treatment for BBS, this finding was based solely on indirect evidence (Supplementary Fig. 1).

There were limitations of this review that should be considered. Firstly, we were not able to produce meaningful comparison adjusted funnel plots to explore small study effects in the NMA. This was due to the small number of studies reporting direct comparisons between exercise interventions and non-exercise controls and there was no meaningful way to order interventions in the funnel plot, which is an essential criterion to produce meaningful comparison adjusted funnel plots [62]. Secondly, the analysis did not factor in the age of menopause onset, which predicts future fall risk and symptom severity [6] and could be considered a confounding factor when examining the effects of exercise on balance. However, age of menopause was not universally reported in

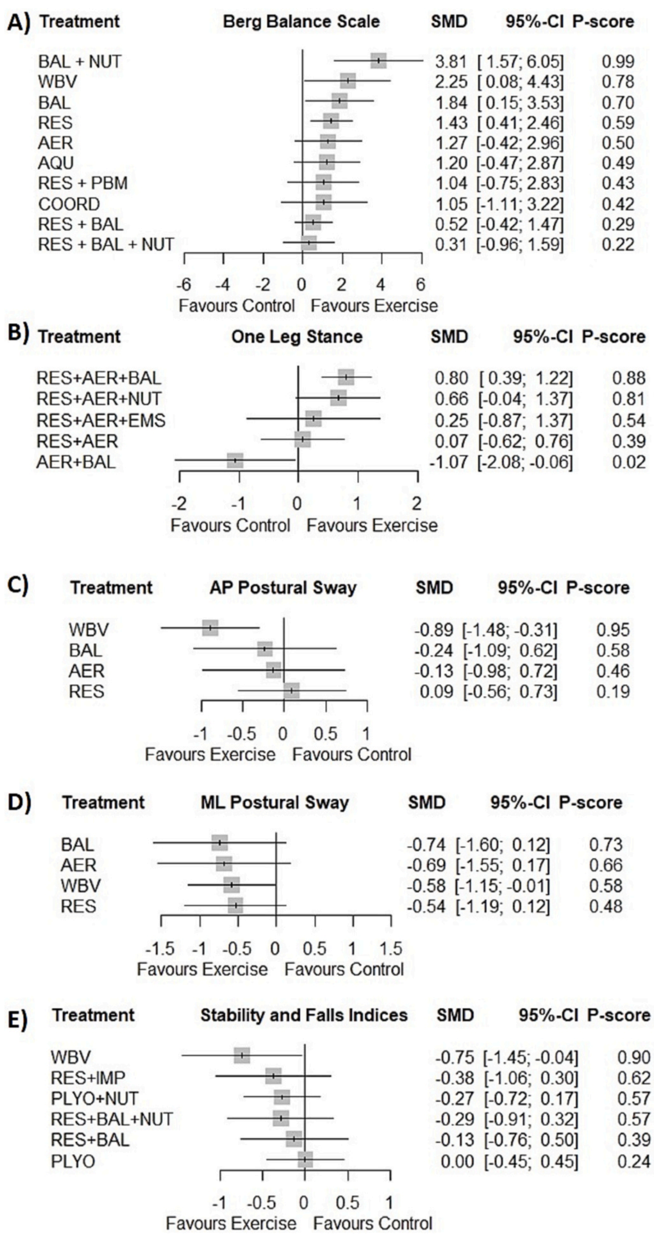

Fig. 3. Forest plots indicating the standardised mean differences (SMD) with 95 % confidence intervals (CI) for A) Berg balance scale, B) one leg stance, C) anterior-posterior (AP) postural sway, D) medio-lateral (ML) postural sway, E) stability and falls indices. In each forest plot individual rows represent the comparison of a treatment type to control, the treatments are ordered by their ranking with the highest ranked treatments at the top (highest P-score).
AER: aerobic, AQU: aquatic exercise, BAL: balance, COORD: coordination, EMS: electromyostimulation, IMP: impact, NUT: nutrition, PBM: photobiomodulation, PLYO: plyometric, RES: resistance, WBV: whole-body vibration. + indicates a combination of treatment types.

the reviewed literature and should be considered an important characteristic to report in future trials.

5. Conclusions

In conclusion, the present systematic review and network meta-analysis of RCTs aimed to determine the effect of exercise interventions on measures of balance in perimenopausal, menopausal and early postmenopausal women. Whilst our analysis did not provide a conclusive indication of the most effective exercise intervention approaches, it does highlight the benefits of exercise on balance in this population. At least one form of exercise intervention resulted in significant improvements in all the analysed balance variables. WBV appears to have the largest effect on balance measures when compared to non-exercise controls, however, caution should be taken when interpreting this outcome as this was derived from small studies and in the case of the BBS from indirect evidence only. Additionally, both resistance and balance training improved BBS performance and combined resistance + aerobic + balance training improved OLS. Changes in balance performance are likely the result of complex interaction of somatic and psychological factors.

Contributors

Gregory S Walsh contributed to conception and design, search and screening, statistical analysis, and drafting and revision of the paper for important intellectual content.

Anne Delextrat contributed to conception and design, search and screening, and drafting and revision of the paper for important intellectual content.

Adam Bibbey contributed to conception and design, search and screening, and drafting and revision of the paper for important intellectual content.

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The authors declare that they have no competing interest.

Appendix A. Supplementary data

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