REVIEW ARTICLE

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Efficacy of Progressive Resistance Training on Balance Performance in Older Adults

A Systematic Review of Randomized Controlled Trials

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Abstract

The serious health, social and economic consequences of falls are well documented. Lower extremity muscle weakness and power as well as balance impairment are major independent intrinsic contributors to falls and amenable to intervention. Progressive resistance training (PRT) is widely accepted as an appropriate modality for treating sarcopenia and has been reported to improve balance. However, other studies affirm no significant effect of PRT on balance.

To date, there is no clear, definitive statement or synthesis of studies that has examined the effect of PRT on balance. Therefore, our objective was to systematically review the literature to probe the merit of PRT as a single intervention on balance performance in older adults. We conducted a comprehensive search of major electronic databases to October 2006, with citation searches and bibliographic searches of journal articles and literature/systematic reviews. Two independent reviewers screened for eligibility and assessed the quality of the studies using the Physiotherapy Evidence Database scale for validity assessment. Randomized controlled trials of PRT only, with any balance outcome in participants with a mean age of ≥60 years (individual minimum age >50 years) were included. Trials that contained more than one intervention, providing the PRT and control groups matched the inclusion criteria, were also included. Because of the heterogeneity of interventions and balance outcomes, a meta-analysis was not performed. However, corrected effect sizes with confidence intervals were determined for each study outcome. Twenty-nine studies were compatible with the inclusion/exclusion criteria and were eligible for review. Participants (n = 2174) included healthy, community-dwelling, mobility-limited, frail cohorts and those with chronic comorbidities. Balance outcomes conducted were extensive and were broadly categorized by the authors as: static, dynamic, functional and computerized dynamic posturography. Some studies used more than one balance outcome. The number of balance tests in all totalled 68. Fourteen studies (15 tests representing 22% of all balance tests) reported improvements, significantly greater than controls, in balance performance following PRT. Improvements were not linked to a particular type of balance performance. The inconsistent effect of PRT on balance may be explained by heterogeneity of cohort and balance tests, variability in methodology of the balance test and sample size, inadequate dose of PRT and/or compliance to training, or lack of statistical power. Standardization of balance testing methodology and better reporting of procedures may ensure greater comparability of results in future studies. It is also possible that PRT alone is not a robust intervention for balance control. This is the first systematic synthesis of the literature to examine the effectiveness of PRT alone on balance performance in older adults. The limited evidence presented in currently published data has not consistently shown that the use of PRT in isolation improves balance in this population. However, further research should explore optimal resistance training regimens that: focus on the muscles most pertinent to balance control, best target neuromuscular adaptations that protect against postural challenges and elucidate mechanism(s) by which PRT may affect balance control.

Functional decline and frailty, serious clinical sequelae of a fall, make falls a major public health concern. Falls are mulifactorial in origin. Although dizziness, postural hypotension, depression, cognition, visual disturbance and slow reaction time are associated with falls,[1] lower extremity muscle weakness and balance impairment (balance dysfunction or postural instability) have been identified as major independent contributors to falls.[1-4] Fallers have lower quadriceps,[4] ankle dorsiflexor[5-7] and ankle plantarflexor[5,7] muscle strength than non-fallers. Similarly, poor balance was strongly associated with falls risk in community dwelling[6,8] and institutionalized older adults[9] and stroke patients.[10]

Loss of strength has been observed to be associated with a decline in functional performance,[11,12] thus prompting the investigation of muscle weakness as a contributor to balance itself. Increased ankle plantarflexor,[13] knee and hip strength[14] was associated with better standing balance in healthy[13] and disabled[14] older adults. Furthermore, a strong relationship between decline in strength and poorer balance performance has been identified in community-dwelling older adults and nursing home residents.[15]

More recently, lower leg power has been observed to contribute to poorer functional performance[16] and is suggested to be a better indicator of falls risk than strength.[17] The age-related reduction in muscle power appears to be determined by impaired contraction velocity, as well as muscle mass/force-generating capacity. This attenuated ability to contract postural muscles rapidly may contribute to an increased risk of falls.[18] Elderly fallers demonstrated lower leg power than non-fallers[17] and reduced leg power has been shown to be an early indicator of balance deficits.[19]

Because sarcopenia and muscle weakness are factors amenable to improvement, progressive resistance training (PRT) [strength training exercise with progressive overload where muscles exert a force against an external load or contract isometrically] has been widely accepted as an appropriate modality of treatment. Gains in strength following PRT may be accompanied by improved body composition, metabolic health, blood pressure, cognition, depressive symptomatology, sleep and reaction time, making PRT an efficacious intervention in terms of time and effort for older adults. Power training, performed with a fast-velocity concentric action and slow eccentric action, is considered as a specific form of resistance training. PRT and power training have been reported to improve balance performance.[20-33] In contrast, a recent systematic review and meta-analysis of the effect of PRT on physical function could find no apparent merit of PRT on standing balance in 12 studies.[34] Moreover, the FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques)[35] and Moreland et al.[3] meta-analyses lacked supporting evidence for a significant effect of PRT on falls events.

The literature examining PRT and balance performance is characterized by an extreme heterogeneity in populations, training regimen (dose, mode, progression) and balance outcome variables making clear comparisons between studies difficult. There has been no clear definitive statement or synthesis of these studies. Few studies have closely examined whether the dose of resistance exercise determines a positive balance outcome, an aspect critical to the design of optimal exercise programmes to enhance balance. Furthermore, no 'gold standard' of clinical balance exists, and numerous and varied tests have been devised to assess and quantify different components of balance/postural stability, each having their own merits and limitations. Therefore, our objective was to present the first systematic synthesis of evidence from randomized controlled trials (RCTs) in order to determine the efficacy of PRT as a singular intervention on balance performance in older adults. Due to the heterogeneity of key variables, a meta-analysis was not performed.

1. Methods

1.1 Search Strategy

Electronic database searches were performed in: CINAHL, Cochrane Central Register of Controlled Trials, Cochrane Musculoskeletal Injuries Group, Cochrane Reviews, MEDLINE, SportDiscus, EMBASE, Science Direct, Current Contents, Web of Science; PEDro and PubMed, from earliest record to October 2006. Permutations of keyword combinations for the following categories were used:

1. Intervention: resistance/strength/power/weight training/exercise, randomized trials, and clinical trials.
2. Participants: aged, elderly, geriatric, older adults, or senior.
3. Outcome: balance, postural stability, postural control, body sway, or neuromuscular performance.

Bibliographies of all eligible papers and systematic reviews identified from electronic database searches were manually searched for any papers missed by the database searches. Non-English papers were included, but excluded if translation was unsuccessful.

1.2 Inclusion and Exclusion Criteria

Potentially relevant papers describing RCTs that investigated PRT as an exercise intervention and balance performance as an outcome in older adults, were examined.

Studies of older, men or women, mean age ≥60 years (minimum age 50 years) were considered. Participants could include healthy, community-dwelling cohorts, nursing home residents, frail, mobility- or functionally-limited adults or persons with pathology.

We examined RCTs in which one group performed PRT or power training. Studies that included balance training or multimodal training (i.e. training additional to resistance exercise) were excluded. PRT could be conducted by a number of modalities, for example, weights machines, free weights, isometric exercise, elastic tubing (Therabands™)**1** or other equipment (weighted vests/belts/balls, soft weights, rice bags, filled water bottles).

RCTs in which participants assigned to the control group participated in usual daily activity/usual care, or activities that enhanced the blinding of the intervention, e.g. sham exercise, flexibility training, educational seminars, were considered.

All modes of static, dynamic and functional balance performance and postural challenge assessment (computerized dynamic posturography) were included in this review. Descriptions of the types of tests used to assess balance performance in this review are presented in table I. Static balance is defined as the ability to maintain the centre of gravity over a narrow base of support in an upright position.[36,37] Dynamic balance is the ability to maintain equilibrium whilst the body's centre of gravity is in motion (i.e. the centre of gravity does not stay within the base of support). Functional balance assesses whether a balance problem exists, predicts falls risk or assesses the ability to carry out everyday tasks or activities.[37] Computerized dynamic posturography assesses postural stability on a computer-interfaced dynamic force platform. This test allows the quantitative examination of balance under static and dynamic conditions and can test sensory organization and reactions to surface displacement.

1.3 Selection

All papers identified by the search strategy were screened independently by two researchers (RO and JR), first by title and then by abstract using the eligibility criteria. Any differences were resolved by discussion and mutual consent, or by a third assessor (MFS). We did not include abstracts and conference papers from annual meetings because of the paucity of data. Remaining papers were retrieved for further scrutiny to determine eligibility. If data provided were insufficient, we attempted to contact authors for further information.

1.4 Data Abstraction

Data were extracted on to pretested standardized forms using the following headings: Study Characteristics: *Study Design* (including *Statistical Analysis*), *Participant Characteristics, Intervention Characteristics, Control Activities* and *Balance Outcome Measures* and Balance Outcomes.

1.5 Quantitative Data Synthesis and Validity Assessment

The primary outcome was change in balance performance. Because of the heterogeneity of balance tests used and outcomes measured, we used the standardized difference method as the effect size (ES) measure. ES was determined by subtracting the mean change in balance outcome in the PRT group from the mean change in balance outcome in the control group, and dividing the difference by the pooled baseline standard deviation of the PRT and control groups.[48] The ES was then corrected for small-sample bias.[49] A weighted mean difference was calculated as the difference in means of the change scores in the intervention and control groups, using the method of the Cochrane Collaboration group.[50] For studies that included multiple outcomes (e.g. more than one balance test performed, or one group training at high intensity and one training at low intensity, or at differing weekly frequency), each balance test was treated independently.

Some studies performed *a priori* or *post hoc* power testing based on primary outcomes. Because power analysis may have been performed on outcome measures other than balance performance in these studies, *post hoc* power testing was completed on balance data using the *G*Power* power analysis

1 The use of trade names is for product identification purposes only and does not imply endorsement.

Table I. Assessment of balance performance by balance type

Balance test	Description of balance test	Balance measure	Reliability/validity of measure
Static, eyes open and/or eyes closed			
Single-leg stance	Stand on one leg with other leg flexed, allowing foot to clear the floor and balance as long as possible. No assistive devices are permitted[36,38]	Time up to 5–60 sec or as long as possible without grasping for support or moving feet (most studies use 30 sec)	Validity demonstrated by relationship with gait performance, falls status, IADL, frailty[39]
Parallel stance, double-leg stance, Classic Romberg	Feet placed together, side by side[36,38]	Time up to 10–30 sec, without grasping for support or moving feet	Reproducibility coefficients 0.7–0.99[38]
Semi-tandem stance	Toe of one foot placed adjacent to heel of other foot[36,38]	Time up to 10–30 sec	
Tandem stance, Sharpened Romberg	Heel of one foot placed directly in front of toe of other foot[36,38]	Time up to 10–30 sec	
FICSIT-3 (or -4)	Combined parallel, semi-tandem, tandem stance (plus single-leg stance)	Score 0–4 (0–5),[a] determined by the time each stance could be held for, up to 10 sec	r = 0.66 over 3–4 mo test-retest interval[36]
Postural sway on compliant surface[6]	Tandem stance on a 15-cm thick medium-density foam rubber mat, wearing swaymeter (40-cm rod attached to waist by a belt and extends posteriorly. A pen mounted at the end of the rod records sway excursions on graph paper)	Sway path (mm) traced in 30 sec	Test-retest reliability coefficients (n = 37). Eyes open: r = 0.81; p < 0.01 (95% CI 0.66, 0.90), Eyes closed: r = 0.73; p < 0.01 (95% CI 0.53, 0.85)[6]
Balance ability on a tilt board[38]	Stand with feet perpendicular to tilt board's rotational axis to measure anterior-posterior or omni-directional instability	Time up to 30 sec	
Dynamic, eyes open and/or eyes closed			
Tandem walk – forward or backward	Walk as quickly and carefully as possible placing one foot directly in front of (or behind) the toe (heel) of the other foot without making errors (i.e. when one foot is not placed in contact with the other, taking a step to the side)	Time (average of 2 trials), number of errors	Test-retest (1 wk) r = 0.94[22]
Functional reach[40]	Maximum distance that can be reached forward beyond arm's length while maintaining a standing fixed base of support. Predictive of recurrent falls risk	Mean distance achieved over 3 trials or score 0–3[b] determined by distance reached. Two practice trials allowed	CV = 2.5%, ICC = 0.92, ICC (intertester) = 0.98
Balance beam walk[38]	Walk as quickly as possible along a narrow (8.5 cm) or wide (17 cm) beam over a distance of 6–9 m	Time on beam(s), distance walked before stepping off (m)	

Continued next page

Table I. Contd

Balance test	Description of balance test	Balance measure	Reliability/validity of measure
Functional			
Berg Balance Test[10,41]	Level of balance quantified by 14 tasks: sit to stand, stand to sit, transfers, standing with feet together, with eyes closed, with one foot in front, on one foot, reaching forward, retrieving an object from the floor, turning to look behind, turning 360°, placing alternate foot on stool	Score 0–56[c] determined from an ordinal scale of 0 (cannot perform) to 4 (can perform) for each of the 14 activities	Inter-rater reliability coefficient = 0.98, intra-rater reliability coefficient = 0.98, internal consistency Cronbach's α = 0.96. Correlations with laboratory measures of sway (–0.55), global ratings of therapists (0.81) and care-givers (0.47–0.61)[10]
CS-PFP – balance and coordination domain[42]	Functional tasks included transferring laundry, donning and removing a jacket and seatbelt, sweeping, vacuuming, bed making, stair climbing, getting in and out of a bathtub	Score 0–12 (average of 5 standardized and summed domain scores).[d] Separate domain scores given. The tasks are quantified by time, distance or weight. CS-PFP balance and coordination is derived from tasks quantified by time	Inter-rater reliability coefficient = 0.99, test-retest coefficient = 0.96, Cronbach's α = 0.91. CS-PFP-B&C correlated with the 5 physical performance capacity measures it reflected (r = −0.21 to −0.91)[42]
ADAP – balance and coordination domain[24]	16 common functional tasks, such as transferring laundry, boarding a bus performed at peak effort. The test is modelled on CS-PFP	Score 0–100 for each task. The tasks are quantified by time (speed), distance or weight.[e] ADAP – balance and coordination is derived from tasks quantified by time	ICC total score = 0.96, ICC domain scores = 0.75–0.95[24]
Computerized dynamic posturography, computerized balance platforms or force plates[f]			
Chattecx Dynamic Balance System[43]	Single- or double-leg stance, static platform, double-leg stance on platform moving forward and backward, double-leg stance on platform tilting up and down (4° amplitude, frequency 1 Hz)	Time up to 30 sec. Sway amplitude (cm). Loss of balance	ICC = 0.41–0.90) ICC = 0.06 (double-leg stance, static platform, eyes closed)[44]
Sensory Organisation Test[g] using EquiTest[45]	The platform's support surface and visual surround are fixed or can sway with the participant (sway referenced). Three consecutive 20-sec trials are given in each of 3 visual (eyes open, eyes closed, sway-referenced) and 2 support (fixed, sway-referenced) conditions. Timing and magnitude of surface forces are measured in response to these perturbations	Functional base of support. Equilibrium quotient (sway within and exceeding limits of stability). Balance strategy score (Newtons shear force/kg body mass). Loss of balance when sway exceeds limits of stability (8.5° anteriorly, 4° posteriorly)	ICC (1 week apart) = 0.15–0.7 for first trial and 0.26–0.68 for average of 3 trials[46]
Motor Coordination Test using EquiTest[45]	Double-leg stance on platform that provides a series of sudden anterior and posterior translations (250, 300, 400 msec duration) and toes-up, toes-down rotations (8° amplitude, 400 msec duration)	Latency – time (msec) from perturbation to actively resisting sway. Sway momentum	
Balance Master[47]	Move centre of gravity as quickly as possible to attain 8 targets set at 75% of their limits of stability. Visual conditions: eyes open, eyes closed or with visual feedback	% postural sway with eyes open, eyes closed, and with video feedback. Total number of 75% limits of stability targets attained. Time taken to attain each target	

a FICSIT-3 score = 0–4, FICSIT-4 score = 0–5: 0 = unable to perform parallel stance; 0.5 = parallel stance held <10 sec; 1.5 = parallel stance held for 10 sec, semi-tandem stance <10 sec; 2.0 = parallel and semi-tandem stance held for 10 sec, unable to perform tandem stance; 3.0 = parallel and semi-tandem stance held for 10 sec, tandem stance <10 sec; 4 = all 3 stances held for 10 sec; 5 = all 4 stances held for 10 sec.[36]

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Table I. Contd

b Functional Reach score 0–3: 0 = unable or unwilling to reach; 1 = reach ≤6 inches (15.2 cm); 2 = 6 inches < reach < 10 inches (25.4 cm); 3 = reach ≥10 inches. Relative risk for falls: 0 = 28 times more likely to fall; 1 = 4 times more likely to fall; 2 = 2 times more likely to fall; 3 = not likely to fall.[40]

c Berg Balance Test score 0–56. The Berg Balance Test rates the ability to maintain balance when performing 14 movements used in everyday tasks. For scores of 54–56, each 1 point drop is associated with a 3–4% increase in fall risk. For scores of 46–55, each 1 point drop is associated with a 6–8% increase in fall risk. A score <45 reflects those unsafe in independent ambulation.[10] A score <36 indicates close to 100% risk of falls.

d The CS-PFP is a comprehensive measure of physical functional performance. Fifteen everyday tasks of independent living are summarized in 5 physical domains that reflect upper- and lower-body strength, upper-body flexibility, endurance and balance and coordination.[42] Measures of time, weight and distance are transformed to standard scores and scaled 0–12. The lowest 10% of scores are designated as 1 and highest 10% scored as 12. Scores between the 10th and 90th percentile are grouped into 8 percentile bands and scored as 2–11. Inability or refusal to perform task scores zero. The total CS-PFP is the sum of the standard scores, scaled 0–12.

e The ADAP is a comprehensive measure of physical functional performance comprising 16 common tasks that are summarized in 5 physical domains that reflect upper- and lower-body strength, upper-body flexibility, endurance and balance and coordination. ADAP provides a total score and 5 physical domain scores. Each task was scaled from 0 to 100.[24]

f Assess postural stability is represented by movements of the centre of mass, on a stable and/or moving, destabilizing/perturbating surface, with eyes open and/or closed.

g The Sensory Organisation Test evaluates which of the senses (visual, vestibular or somatosensory) [or combinations] and motor strategies contribute to balance deficits. The 6 conditions are: (1) eyes open/firm surface; (2) eyes closed/firm surface; (3) sway referenced vision/firm surface; (4) eyes open/sway-referenced surface; (5) eyes closed/sway-referenced surface; and (6) sway referenced vision/sway-referenced surface.

ADAP = Assessment of Daily Activity Performance; **CS-PFP** = Continuous-Scale Physical Performance Score; **CS-PFP-B&C** = CS-PFP Balance and Coordination domain; **CV** = coefficient of variation; **FICSIT** = Frailty and Injuries: Cooperative Studies of Intervention Techniques; **IADL** = instrumental activities of daily living; **ICC** = intra-class correlation coefficient.

program.[51] As a consequence of the heterogeneity of interventions, balance outcomes and cohorts, a meta-analysis was not performed.

Quality assessment of eligible papers was undertaken independently by RO and JR using the Physiotherapy Evidence Database (PEDro) scale,[52] an 11-item scale that includes the 3-item Jadad scale[53] and 9-item Delphi list.[54] The PEDro scale rates RCTs from 0 to 10. One question is used to establish external validity and is not included in the score. The PEDro scale reports an inter-rater reliability intraclass correlation coefficient (ICC) = 0.68 (95% CI 0.57, 0.76). Any differences were resolved by discussion and mutual consent or rating by a third assessor (MFS).

2. Results

The flow of papers, from potentially relevant to selection, from January through October 2006 is displayed in figure 1. A total of 29 studies were eligible for review according to the inclusion/exclusion criteria. Thirty-seven of the 66 papers retrieved were excluded for the following reasons: utilized combined training programmes, not isolated PRT[55-70] balance training,[71,72] not PRT,[73-75] no progression of resistance training,[76] not a RCT,[77-85] balance outcome not included,[86,87] mean age <60 years,[88] or the paper contained the same cohort or was a preliminary paper to one included in this review.[89-91]

2.1 Study Characteristics

2.1.1 Study Design

Of the 29 single-blind RCTs, one study was a multicentred study[92] and two were conducted at two sites.[26,93] Most RCTs consisted of a PRT group and a control group; four studies comprised four groups;[32,33,94,95] and eight studies included three groups.[23-28,31,93]

2.1.2 Quality Assessment and Validity

Quality assessment and internal validity of the included trials are summarized in table II and table III. The inter-rater correlation of PEDro scores between the researchers was 0.9, greater than reported by PEDro raters.[52] Two studies randomized more participants to PRT because of greater anticipated

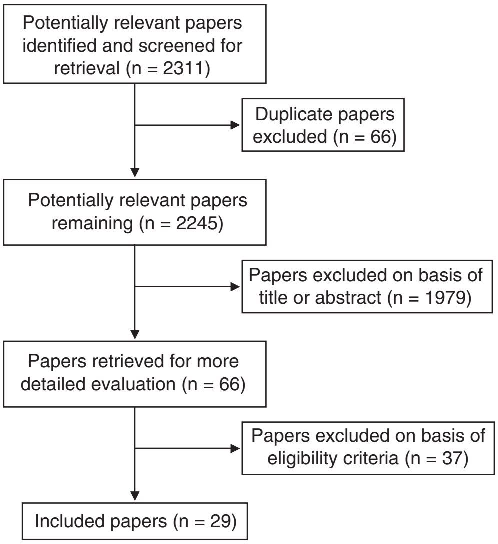

Fig. 1. Flow of papers from potentially relevant to selected for review.

withdrawals from the control group.[93,96] Twelve papers (43% of studies) comprising 39% of all balance tests scored ≥6 on the PEDro scale, signifying better quality studies.

2.1.3 Participant Characteristics

A total of 2174 participants were randomized (1020 to PRT, 866 to control, 268 to other modes of training, 20 not specified[29]). Most participants were healthy and community-dwelling (n = 1090).[21,22,24,27,29,32,33,47,94,95,99,101,103-105] Six RCTs[11,28,31,96,100,102] comprised functionally impaired or mobility-impaired participants (n = 432). Frail (n = 383)[30,92,93] and institutionalized participants (n = 20)[98] and individuals with coronary heart disease (CHD) [n = 42],[20] osteoarthritis (n = 103)[26] and low bone mass (n = 243)[25] were also eligible for inclusion in this review. The mean age of all participants ranged from 60–88 years and 68.3% were women. Not all studies reported ages for the intervention groups, but the average age ranged from 61 to 88 years where reported, and was comprised of 70% women. The average age of control group participants ranged from 57 to 88 years where reported, and was comprised of 70.7% women. One study contained only men[29] and seven studies examined women only.[22,24-26,28,30,104] Major co-morbidities included CHD, osteoarthritis, osteoporosis, hypertension, type 2 diabetes mellitus, respiratory and kidney disorders and cancer. Studies were conducted in Australia,[21,32,101] Canada,[25] Finland,[30] the Netherlands,[24,93,96] New Zealand,[92] Portugal,[29] the UK[47,104] and the US.[11,20,22,23,26,27,31,33,47,94,95,98-103,105] Ethnicity, although not well reported, was principally Caucasian (76.5–100%), with African American (7–34%) and Asian (7%) cohorts also participating. The groups were generally comparable at baseline. Some studies indicated some significant baseline differences in age, weight, body composition, ankle and handgrip strength or function.

2.1.4 Intervention Characteristics

The intervention and control group characteristics are shown in the supplementary material ['ArticlePlus'] at http://sportsmedicine.adisonline.com. A total of 852 (from 1020) completed PRT and a total of 126 participants (range 0–18 per study) were reported as withdrawals. Attrition rates averaged 13%, and varied greatly between the studies from 0%[11] to 39%,[31] with three RCTs not specifying intervention withdrawals.[26,29,102]

Setting and Training Equipment

Interventions were mainly conducted in a gym/community setting;[11,21,22,24-27,30,32,33,94,95,98,101] combined gym and home-based location[28,47,93,96,104,105] or were solely home-based programmes.[92,100,102] Some studies did not report a training venue, but a gym/community setting was likely from the description of training equipment.[20,29,31,99,101,103]

A diversity of training equipment was used: pneumatic[22,25,31,32] and weight-stack[20,23,29,30,33,95,101,103] resistance training machines; free weights;[20,21,24,26,27,92,98] elastic bands/tubing;[24,28,47,93,96,98,100,102,104,105] body weight;[27,28,93,96,104] and weighted equipment such as balls, vests, rice bags, sandbags[11,27,28,33,98,104] solely, or in combination. Twenty studies used a single type of training equipment (12 used resistance training machines,[22,23,25,29-32,94,95,99,101,103] three used free weights,[21,26,92] four used elastic bands/tubing,[92,100,102,105] one used weighted vests[11]) and nine studies used a combination of equipment.[20,24,27,28,33,93,96,98,104]

Table II. Quality assessment and internal validity of studies

Randomization process	Allocation concealment	Baseline comparability	Assessor blinding	ITT analysis	Attrition rate (% with-drawals)	*A priori* power testing	*Post hoc* calculation of power of balance tests[a]	Methodological quality (0–10)[b]	Reference
Stratified by physical function domain of SF-36	NR	Yes	NR	No	21	NR	0.71	4	20
Computer-generated random numbers list	Stated, but no specific information given	Yes	Yes	No	9	No	0.59	8	21
Computer-generated algorithm (permutated blocks) stratified by residence	Sealed envelopes	Yes	Yes	Yes	10	Yes	0.10	8	98
NR	NR	Yes	Yes	NR	0	No	0.15	6	11
NR but more randomized to RT because of greater anticipated withdrawals from control group	NR	Yes	Yes, but not the same assessor for pre- and post-measures	No	32	Yes, but proved to be insufficient power	0.06–0.22	4	93
NR	NR	Yes	NR	No	20	Yes	0.05	5	99
Randomly permutated blocks	NR	Yes	Yes	No	12	*Post hoc*	0.05–0.15	7	94
Block randomized and stratified by level of function	NR	Yes	Yes	No	12	No	0.06	6	100
Computer-generated random numbers table	NR	Yes	Yes verified blinding status, 37% correct	NR	17.6	Yes	0.32	6	24
NR	NR	Yes	NR	NR	10.4	NR	0.05–0.12	5	101
Randomly permutated blocks of 4 by staff not involved in data collection	NR	Yes	Yes	No	7	No	0.05–0.39	6	102
Computer-generated randomization sequence in blocks of 6	No	Yes	Yes verified blinding status, <38% correct	Yes	6.7	Yes	0.30	8	92
Stratified by baseline postural sway	NR	Yes	Yes	Yes	6	Yes	0.80	7	25
Stratified variable, block randomized to give even numbers in each group	NR	Yes	NR	No	NR	NR	0.09–0.88	4	26
Stratified by sex	NR	Yes	No	NR	31.4	*Post hoc*	0.05–0.42	4	31
NR	NR	No	NR	Yes	4.8	NR	0.46	5	22

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Table II. Contd

Randomization process	Allocation concealment	Baseline comparability	Assessor blinding	ITT analysis	Attrition rate (% withdrawals)	*A priori* power testing	*Post hoc* calculation of power of balance tests[a]	Methodological quality (0–10)[b]	Reference
NR	NR	NR	NR	No	5	NR	0.46	5	23
Computer-generated random numbers list, blocks of 4, stratified by sex	Serially numbered opaque sealed envelopes	Yes	No	No	8.9	Yes	0.10–0.39	6	32
NR	NR	Yes	No	Yes	19	No	0.26–0.94	5	27
NR	NR	NR	NR	No	8.3	No	0.05	5	103
Random numbers table after matching for age and habitual physical activity	NR	Yes	No	No	16.7	Yes	0.21	5	104
20 matched for age then randomized, but one participant 'chose' training group	NR	Yes	NR	No	10	Yes	Cannot calculate	4	28
NR	NR	NR	NR	NR	NR	NR	0.74	2	29
NR	NR	Yes	NR	No	14.7	Yes	0.24–0.75	5	95
Randomized in blocks of 4	Closed envelopes	Yes	NR	Yes	23.5	No	0	6	30
NR	NR	Yes	No	No	19	*Post hoc*	0.05–0.21	5	105
NR	NR	No	NR	No	34	NR	0.05–0.73	3	47
NR, but more randomized to RT because of greater anticipated withdrawals from control group	NR	Yes	Yes	No	8.3	NR	0.05–0.06	5	96
Blocked allocation schedule generated by algorithm and stratified by sex	NR	Yes	Yes	No	3.8	*Post hoc*	0.06–0.23	6	33

a *Post hoc* calculations were performed by the authors using *G*Power*.[51]

b Methodological rating based on Physiotherapy Evidence Database (PEDro) score.[52]

ITT = intention-to-treat; **NR** = not reported; **RT** = resistance training; **SF-36** = Medical Outcomes Study Short Form-36.[97]

Table III. Summary of the numbers of trials reporting the characteristics of study design described in table II

Characteristic of study design	Yes no. of trials	Yes references	No no. of trials	No references	Not reported no. of trials	Not reported references
Method of randomization	16	20,21,24-26,28,30-33,92,94 98,100,102,104			13	11,22,23,27,29,93,95 47,96,99,101,103,105
Allocation concealment	4	21,30,32,98	1	92	24	11,20,22-29,31,33 47,93-96,99-105
Baseline comparability	24	11,20,21,24-28,30-33,92-95 96,98-102,104,105	2	22,47	3	23,29,103
Blinding of assessors	12	11,21,24,25,33,92-94,96 98,100,102	5	27,31,32,104,105	12	20,22,23,26,28-30,95 47,99,101,103
Power testing	10	24,25,28,32,92,93,95,98,99,104	6	11,21,30,100,102,103	9	20,22,23,26,27,29 47,96,101
	4[a]	31,33,94,105				
ITT analysis	6	22,25,27,30,92,98	18	20,21,23,26,28,32,33,93-95 47,96,99,100,102-105	5	11,24,29,31,101
Attrition	26	11,20,22-25,27-29,32,33 47,92-96,98,99,101-105			3	21,31,100

a *Post hoc.*

ITT = intention-to-treat.

Training Prescription

The prescription of PRT was generally well described. The study duration averaged 22.7 weeks (range 8–104 weeks). The mean training session duration was 58.8 minutes (range 35–90 minutes) and frequency of training was 2–3 days/week. Two to three sets per session were prescribed in all studies.

Studies using resistance machines quantified the training intensity most objectively using percentage of one repetition maximum (1RM);[20,22,23,25,29-33,92,94,95,99,101,103] some also used subjective assessment, i.e. ratings of perceived exertion (RPE).[20,22,32,33] Several studies prescribed variable intensity in each session. For example, each of the three sets was performed at successively increasing intensities of 50%, 60% and 70% 1RM,[99] or intensity varied according to the exercise: shoulder press was performed at 45% 1RM, chest press at 50% 1RM, and fly at 60% 1RM.[23] Four studies used RPE alone,[11,21,24,102] but Jette et al.[102] did not specify the value. Skelton et al.[104] prescribed intensity at <70% heart rate reserve. Five studies did not report intensity,[26,28,98,100] but the methodology suggested training was performed at relatively low intensity. Four studies used power training; one at 40% 1RM,[31] one at 20%, 50% and 80% 1RM,[32] one at increasing loads with each set (45%, 60% and 75% 1RM)[101] and the other at moderate intensity using weighted vests.[11] We categorized studies according to training intensity: high (≥70% 1RM),[20-22,25,30-33,94,95,103] moderate (41–69% 1RM),[11,23,24,29,32,47,92,99,104,105] and low (≤40% 1RM).[26,27,31,32,93,96,98,100,102,104]

Progression

Although described in all studies, the protocol for progression was somewhat diverse. Training load was increased: following 1RM testing 1-,[32] 2-,[38,92,103] 4-[20,22,29,31,95,99] and 6-weekly;[23] by maintaining RPE;[21,24] when a number of repetitions or sets and repetitions were achieved;[25,26,28,93,96,100,101,104] when fatigued;[47] when possible;[27] or with no details other than ‘as muscle strength increased’.[30]

Supervision and Compliance

Training was fully supervised in 18 of 29 cases,[11,20-22,24,25,27,29,30,32,33,93,95,96,98-101] with five studies explicitly reporting supervision by trained staff;[20,21,24,32,96] whereas 11 studies were unsupervised,[92] monitored intermittently[28,47,102,104,105] or supervision not reported.[23,26,31,94,103] Twenty-five of 29 studies reported compliance rates;[11,20,22-29,32,33,47,92-96,98,99,101-105] three studies did not.[21,31,100] One study described compliance to training as ‘satisfactory’.[30] Overall compliance to training at gym sessions ranged from 29% to 100% attendance. Compliance to training ranged from 70% to 100% attendance at gym sessions on average; however, two studies reported individual participation rates in PRT as low as 29%[93] and 47%.[27] Overall compliance to home-based training was monitored by training diaries (supported by a booklet[93,96]) and reported to be 69–88%. Individual home-training adherence rates were reported as low as 10%[93] and one study noted that participant reporting in the training logs was not good.[96] Research staff paid home visits and gave regular phone calls to maximize adherence.[34,102] Three studies did not describe participant adherence.[21,31,100]

Adverse Events

Adverse events were reported in 17 of 29 trials,[11,20-22,24,25,27,28,31-33,94,96,98,101,104,105] with 7 of 17 trials reporting no adverse events.[20,27,28,98,101,104,105] Adverse events attributed to training were mainly musculoskeletal in nature and none were reported as serious. These included exacerbation of osteoarthritic pain,[96] trochanteric bursitis, muscle, joint and lower-back pain.

2.1.5 Control Activities

Control group activities varied across the studies and included: no treatment (usual daily activity with no increase in physical activity levels[23,24,95,96,99]), wait-list for an exercise programme on completion of the study,[22,31,32,94,100] attention-control (health educational talks,[26,31,33] group driver education classes,[47,105] phone calls and home visits[92]). Some studies offered alternative exercise, including slow-velocity chair-based exercises with low/no resistance,[11] functional exercises,[30] flexibility/stretching[20,21] and/or deep breathing classes to subjects blinded as to which intervention was the preferred treatment arm.[25] Only Liu-Ambrose and colleagues[25] described the exercises as 'sham'. Some wait-list controls later joined the study as intervention participants[27,28,98,102] or became a combined training group.[101] No control activity details were reported in three studies.[29,93,103]

2.1.6 Withdrawals

In all trials, 1795 participants were reported to have completed the studies; 256 (average 13.2%, range 2.5–31.9%) dropped out. No completion or withdrawal details were reported for a further 123 participants randomized.[26,29,102] A total of 753 (from 1020) participants completed PRT intervention and 126 participants (range 0–18 per study) dropped out from PRT. A total of 644 (from 866) participants completed control activities and 80 participants (range 0–13 per study) dropped out from control activities. Three RCTs did not specify intervention or control withdrawals,[26,29,102] accounting for a further 141 and 142 participants, respectively. PRT attrition rates averaged 13%, and varied greatly between the studies from 0%[11] to 39%.[31] Compliance to control activities also varied between the studies, with withdrawals averaging 11.4% and ranged from 0%[21,22,31] to 23%.[93]

2.1.7 Balance Outcome Measures

In all of the studies reviewed, balance was only one of a number of functional performance outcomes measured. Muscle strength, muscle power, mobility, functional capacity, physical health and cognitive function were also evaluated. Balance was a secondary outcome measure in two studies.[25,92] Balance tests were categorized as static, dynamic, functional or using computerized dynamic posturography (table I). We found that there was substantial variability in the methodological conduct of static and dynamic tests as well as a paucity of specific description, such as which leg was tested (self-selected, dominant, non-dominant, both), whether the test was conducted with eyes open or closed, shoes on or off, the number of practice trials permitted, the number of trials allowed, the distance walked, the period for which the test was conducted, (set duration or for as long as possible) and/or what times were reported (best, mean or total of trials). Some studies permitted one trial only while others permitted up to five trials. Some studies permitted one or two practice trials then recorded the best of three trials.

2.2 Balance Outcomes

Details of balance tests and balance outcomes following PRT are presented in table IV. In studies with two or more groups undertaking PRT under several conditions, e.g. high intensity versus low intensity, or frequency of 3 versus 1 day/wk, or strength training versus power training, each group was treated as having independent data. Furthermore, some studies included more than one balance

Table IV. Balance tests and balance outcomes following progressive resistance training (PRT)

Subjects	PRT	Balance outcome characteristics				Balance results				Reference
	intensity and duration	balance type	balance test	measure (max time, distance, or score)	trials allowed	% change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	
Healthy, CD	MI, 12 wk	Static	SLS EO	NR	Mean of 2			0.00 (−10.65,10.65)	0.00 (−0.53, 0.53)	105
			SLS EC	NR				−0.25 (−1.22, 0.72)[b]	−0.14 (0.67, 0.39)[b]	
		Dynamic	BTW	No. errors over 2.4 m (8 ft)				0.50 (−0.37, −1.37)	0.31 (−0.23, 0.84)	
Healthy, CD	HI, 52 wk	Dynamic	BTW	Time over 6.1m (20 ft)	Mean of 2	−14.3	$p = 0.005$	−5.9 (−10.45, −1.35)[b]	−0.82 (−1.48, −0.17)[b]	22
Healthy, CD	MI, 12 wk	Static	SLS EC (combined right and left leg results)	Time up to 45 sec	2 practice then best and mean of 3		$p < 0.05$	1.62 (−0.08, 3.32)	0.61 (−0.04, 1.25)	23
Healthy, CD	MI, 12 wk	Dynamic	Functional reach	Distance (cm)	NR	1		1.90 (−1.32, 5.12)	0.37 (−0.25, 1.0)	104
Functionally limited, CD	LI, 8 wk	Static	SLS EO	As long as possible	NR, but practice trial given	42		Cannot calculate	Cannot calculate	28
			SLS EC	As long as possible		54	Yes, p NR			
		Dynamic	BTW	NR		8.9				
			Functional reach	Distance (cm)	Best of 3	1				
Healthy, CD	MI, 14 wk	PG (Balance Master)	% Postural sway EO		1			0.04 (−0.02, 0.10)	0.39 (−0.22, 1.00)	47
			% Postural sway EC		1			−0.07 (−0.16, 0.02)[b]	−0.49 (−1.10, 0.12)[b]	
			% Postural sway/visual FB		1			−0.01 (−0.09, 0.07)[b]	−0.08 (−0.68, 0.53)[b]	
			No. 75% LOS targets attained		1			1.52 (0.38, 2.66)	0.81 (0.19,1.44)	

Continued next page

Table IV. Contd

Subjects	PRT intensity and duration	Balance outcome characteristics: balance type	balance test	measure (max time, distance, or score)	trials allowed	Balance results: % change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	Reference
Healthy, CD	HI, 12 wk	PG (Equitest)	LOB during SOT	No. LOB	1			−1.00 (−2.57, 0.57)[b]	−0.39 (−1.01, 0.22)[b]	33
			Functional base of support	Time up to 30 sec	Best of 2			−0.01 (−0.11, 0.09)[b]	−0.08 (−0.83, 0.68)[b]	
		Static	SLS EO				$p \le 0.005$	1.20 (−6.2, 8.6)	0.12 (−0.60, −0.83)	
Healthy, CD	HI, 24 wk	Static	SLS EO	Time up to 10 sec	Best of 2			−1.00 (−5.31, 3.31)[b]	−0.10 (−0.66, 0.45)[b]	94
			Tandem stand EO	10 sec	1			0.0 (−1.56, 1.56)	0.00 (−0.055, 0.55)	
			Standing on tilt board (AP direction)	Time up to 30 sec	1			−3.0 (−6.74, −0.74)[b]	−0.45 (−1.01, 0.11)[b]	
			Standing on tilt board (omni direction)	Time up to 30 sec	1			−2.0 (−6.68, 2.68)	−0.24 (−0.80, 0.32)	
		Dynamic	Wide-beam balance walk	Time over 6 m	1			−0.10 (−0.62, 0.42)[b]	−0.11 (−0.66, 0.45)[b]	
			Narrow-beam balance walk	Time over 6 m	1			0.50 (−0.52, 1.52)	0.27 (−0.28, 0.83)	
Healthy, CD	LI, 40 wk	Static	Tandem stand EO	Time up to 60 sec	1 practice, 3 trials (best or average NR)	16	$p < 0.05$	14.00 (5.13, 22.87)	0.69 (0.24, 1.14)	27
			SLS EO			98	$p < 0.05$	14.8 (6.64, 22.96)	0.80 (0.34, 1.25)	
			SLS EC			9		1.50 (0.22, 2.78)	0.51 (0.07, 0.96)	
		Dynamic	Tandem walk	Time over 3 m (10 ft)		26		−3.50 (−8.68, 1.68)[b]	−0.30 (−0.74, 0.14)[b]	
			Tandem walk	No. of missteps over 3 m		37		−1.30 (−2.59, −0.01)[b]	−0.44 (−0.88, 0.00)[b]	

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Table IV. Contd

Subjects	PRT intensity and duration	Balance outcome characteristics: balance type	balance test	measure (max time, distance, or score)	trials allowed	Balance results: % change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	Reference
Frail, moderately limited, CD	LI, 10 wk	Dynamic	Functional reach	NR	2 practice, then mean of 3 trials			0.20 (−1.10, 1.50)	0.06 (−0.36, 0.49)	100
CD with some physical disability	LI, 24 wk	Static	Single leg-stand EO	Time up to 30 sec	1 practice, then mean of 2 trials	20		−0.15 (−2.28, 1.98)[b]	−0.02 (−0.29, 0.25)[b]	102
		Dynamic	Forward tandem walk	No. of successful steps up to 10				0.81 (−0.13, 1.75)	0.23 (−0.04, 0.50)	
			Functional Reach	Distance (cm)				−0.33 (−1.20, 0.54)	−0.10 (−0.37, 0.17)	
Healthy, CD	HI, 24 wk	Dynamic	BTW 3 d/wk	Time over 6 m	Best of 3			−7.70 (−13.27, −2.13)[b]	−1.16 (−2.04, −0.27)	95
			BTW 2 d/wk					−3.3 (−11.8, −5.2)	−0.55 (−1.39, 0.28)[b]	
			BTW 1 d/wk					−8.70 (−17.30, −0.10)[b]	−0.87 (−1.75, 0.01)[b]	
CD with knee osteoarthritis	LI, 78 wk	Static on force platform	DLS EO	Postural sway distance (in 10 sec)	4 first trial was practice, but not disclosed			−0.05 (−0.13, 0.03)[b]	−0.29 (−0.76, 0.18)[b]	26
			DLS EC				p = 0.001	−0.18 (−0.29, −0.07)[b]	−0.76 (−1.24, −0.27)[b]	
			SLS EO	Time up to 10 sec				1.00 (0.07, 1.93)	0.51 (0.03, 0.98)	
			SLS EC					0.3 (−0.63, 1.23)	0.15 (−0.32, 0.62)	
Functionally limited, CD	LI, 10 wk	Static	FICSIT 3	Time up to 10 sec, score 1–6	NR	26 (CI −17, 69)		0.10 (−0.50, 0.70)	0.15 (−0.71, 1.00)	96
			Tandem stand time	Time up to 10 sec	NR			0.50 (−3.50, 4.50)	0.11 (−0.75, 0.97)	

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Table IV. Contd

Subjects	PRT	Balance outcome characteristics				Balance results				Refer-
	intensity and duration	balance type	balance test	measure (max time, distance, or score)	trials allowed	% change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	ence
Healthy, CD, moderately active	HI, 8 wk	Static	SLS EC	Time up to 30 sec	5 (NR whether best or mean time was recorded)	1		−0.12 (−3.01, 2.77)[b]	−0.04 (−0.87, 0.80)[b]	103
Healthy, CD	HI, 10 wk	Dynamic	Functional reach	Distance (cm)	NR	12.7 ± 3.1	$p < 0.003$	3.60 (0.43, 6.77)	0.71 (0.07, 1.35)	21
Frail, mobility-limited	HI, 10 wk	Functional	Berg Balance Test	Score 0–56	NR	2 (CI −10, 14)	$p = 0.001$	3.10 (−4.77, 10.97)	0.22 (−0.34, 0.78)	30
Disabled women with CHD	HI, 26 wk	Functional	Balance and coordination domain of CS-PFP	Score 0–20	NR		$p = 0.0001$	14.5 (3.33, 25.67)	0.91 (0.19, 1.63)	20
Frail, institutionalized	LI, 52 wk	Functional	Berg Balance Test	Score 0–56	NR			−5.30 (−10.66, 21.26)[b]	0.30 (−0.59, 1.19) [authors report 0.32 [90% CI −0.09, 0.74])	98
Frail, CD	MI, 10 wk	Functional	Berg Balance Test	Score 0–56	NR			−2.00 (−4.78, 0.78)	−0.19 (−0.45, 0.07)	92
Low level of physical function, CD	HI, 16 wk	Functional	Balance and coordination domain of CS-PFP	Score 0–20	NR			−0.40 (−12.25, 11.45)	−0.03 (−0.83, 0.78)	31
	LI (PT), 16 wk		Balance and coordination domain of CS-PFP	Score 0–20	NR		Yes, p NR	10.1 (−0.92, 21.12)	0.75 (−0.08, 1.58)	
Mobility-limited, CD	MI (PT), 12 wk	Static	SLS EO	NR	NR	50		−1.98 (−6.04, 2.08)[b]	−0.44 (−1.33, 0.45)[b]	11
Healthy, CD	MI, 104 wk	Dynamic	Functional reach	Distance (cm)	NR			0.40 (−3.63, 4.43)	0.06 (−0.53, 0.65)	99

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Table IV. Contd

Subjects	PRT intensity and duration	Balance outcome characteristics: balance type	balance test	measure (max time, distance, or score)	trials allowed	Balance results: % change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	Reference
Healthy, CD with low bone mass	HI, 25 wk	Static	Postural sway (standing on foam)	Time up to 30 sec	1	−30.6	$p \le 0.05$	−70.90 (−120.41, −21.39)[b]	−0.71 (−1.21, −0.20)[b]	25
Frail, functionally limited, CD	LI, 10 wk	Static	FICSIT 3 (HG)	Time up to 10 sec	NR			0.20 (−0.62, −1.02)	0.17 (−0.51, 0.85)	93
			FICSIT 3 (MG)					0.30 (−0.09, 0.69)	0.32 (−0.37, 1.00)	
			Tandem stand (HG)					−1.90 (−5.06, 1.26)	−0.42 (−1.11, 0.27)	
			Tandem stand (MG)					0.50 (−2.33, 3.33)	0.12 (−0.56, 0.81)	
Healthy, CD	MI, 12 wk	Functional	Balance and coordination subscale of ADAP	Score 1–5	1		$p = 0.05$	4.20 (−1.28, 9.68)	0.41 (−0.13, 0.95)	24
Healthy, active, CD	MI, 12 wk	Dynamic	Functional reach	Distance (cm)	NR	9.4	$p < 0.001$, $F = 39.23$	8.10 (2.19, 14.01)	1.23 (0.28, 2.19)	29
Healthy, CD	LI (PT), 10 wk	PG (Chattecx)	Balance index	Time up to 30 sec	Best of 3 if LOB occurred	−10.8 ± 12.6	$p = 0.012$	−6.60 (−14.26, 1.06)[b]	−0.48 (−1.03, 0.08)[b]	32
			LOB			−13.0 ± 24.7		−0.40 (−1.16, 0.36)[b]	−0.29 (−0.84, 0.26)[b]	
	MI (PT), 10 wk		Balance index			−2.1 ± 10.4		2.20 (−4.51, 8.91)	0.18 (−0.37, 0.73)	
			LOB			−2.1 ± 22.4		0.30 (−0.40, 1.00)	0.24 (−0.31, 0.79)	
	HI (PT), 10 wk		Balance Index			−0.3 ± 9.6		3.20 (−5.04, 11.44)	0.22 (−0.34, 0.77)	
			LOB			0.1 (33.1)%		0.30 (−0.56, 1.16)	0.19 (−0.36, 0.74)	
Healthy, CD	HI, 8 wk	Static	BTW	Time over 6 m	NR			0.20 (−17.72, 18.12)	0.01 (−0.60, 0.61)	101
		Dynamic	Functional reach	Distance (cm)	NR			7.10 (−10.90, 25.16)	0.24 (−0.37,0.85)	

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Table IV. Contd

Subjects	PRT	Balance outcome characteristics				Balance results				Reference
	intensity and duration	balance type	balance test	measure (max time, distance, or score)	trials allowed	% change ± SD in PRT group[a]	significant between-group effect	WMD (95% CI)	effect size (95% CI)	
	MI (PT), 8 wk	Static	BTW	Time over 6 m	NR			0.30 (−18.42, 17.82)	−0.01 (−0.61, 0.59)	
		Dynamic	Functional reach	Distance (cm)	NR			5.70 (−12.43, 23.83)	0.19 (−0.41, 0.79)	

a Percentage change values are only presented if reported in studies.

b Although negative, sign indicates direction of change favours treatment.

ADAP = Assessment of Daily Activity Performance; **AP** = anterior-posterior; **BTW** = backward tandem walk; **CD** = community-dwelling; **CHD** = congestive heart disease; **CS-PFP** = Continuous Scale-Physical Functional Performance; **DLS** = double-leg stand; **EC** = eyes closed; **EO** = eyes open; **F** = female; **FB** = feedback; **FICSIT** = Frailty and Injuries: Cooperative Studies of Intervention Techniques; **HG** = high-attention group; **HI** = high intensity; **LI** = low intensity; **LOB** = loss of balance; **LOS** = loss of stability; **max** = maximum; **MG** = moderate-attention group; **MI** = moderate intensity; **NR** = not reported; **PG** = posturography; **PT** = power training; **SLS** = single-leg stand; **SOT** = Sensory Organisation Test; **WMD** = weighted mean difference (difference in mean of the change score in the intervention and control group).

test. In the 29 studies reviewed, a total of 68 balance tests with sufficient data points were analysed.

Fourteen studies reported that the PRT group performed from 2% to 98% better than the control group in a balance outcome. Studies that included multiple balance tests may have shown significant improvement in one or some, but not every, balance test. Fifteen of 68 tests (22%) showed significantly improved balance performance following PRT in: single-leg stance (SLS) eyes open,[27,33] or closed,[23,28] double-leg stance eyes open[27] or closed,[26] postural sway on a compliant surface,[25] backward tandem walk,[22] functional reach,[21,29] Berg Balance Test,[30] balance component of the Continuous Scale-Physical Functional Performance (CS-PFP),[20,31] balance component of the Assessment of Daily Activity Performance (ADAP)[24] and combined postural sway and static balance measured by posturography.[32] Two of these studies conducted power training.[31,32] Figure 2 depicts the percentage of balance tests showing statistically significant improvements compared with the total number of balance tests within each of the four balance types. Figure 3 shows the number of tests showing statistically significant improvements compared with the total number of balance tests for each specific balance outcome. Five balance tests in three studies[26,27,95] showed nonsignificant results, but moderate to high ES, suggesting clinically relevant outcomes. The possibility of a type II error, indicating that the studies were underpowered, cannot be discounted. Three studies examined the relationship(s) between a change in strength[100] and/or power[31,32] and a change in balance. No such relationships were detected in any of these studies.

2.2.1 Static Balance

Static balance tests (n = 27) were the most widely used tests, comprising 40% of the total number of balance tests performed. Most studies assessing this outcome used low-intensity training; two used moderate intensity[11,23] and four studies employed high intensity.[25,33,94,101] Participants came from both healthy and frail/clinical cohorts. Six of 29 studies (seven tests, 26% of static tests) showed significantly improved static balance performance. The tests were conducted over 10–60 seconds or for as long as possible,[28] and one to five trials were permitted. In

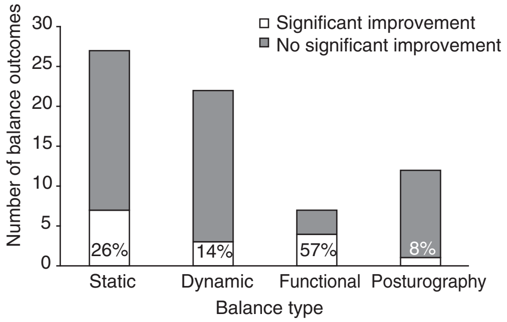

Fig. 2. Balance outcomes stratified by balance type. Studies showing significant balance improvement in: static balance,[23,25-28,33] dynamic balance,[21,22,29] functional balance[20,24,30,31] and computerized dynamic posturography.[32]

the eyes-open condition, SLS and tandem stance (see table I), [predominantly over 10 seconds] were overall not significantly different between control and intervention groups. Two of eight SLS[27,33] and one of five tandem-stance[27] tests showed significantly improved times. These studies employed maximum stance times of 30 and 60 seconds, respectively. No improvements in standing balance over 10 seconds were observed with the FICSIT tests[93,96] or in postural sway on a stable platform.[26]

In the eyes-closed condition, two of five studies showed better SLS time in 57 younger, healthy participants[23] and 18 functionally limited women.[28] Postural sway improved on a stable platform with eyes closed[26] and on a compliant surface such as foam.[25] Most studies used low-intensity training; two used moderate-intensity[11,23] and four studies employed high-intensity training.[25,33,94,103] Participants came from both healthy and frail/clinical cohorts.

2.2.2 Dynamic Balance

Dynamic balance tests (n = 22) comprised 32% of the total balance tests performed. Most studies of dynamic balance used moderate-[29,99,101] or high-intensity training on resistance machines;[21,22,94,95,101] three studies used low-intensity training with elastic tubing.[28,102,105] Participants were generally healthy or frail/mobility-limited.[28,100,102] Three of 29 studies (three tests, 14% of dynamic tests) showed significantly improved balance performance. The distance covered in the tests ranged from 1.8 to 9.1 m (6 to 30 ft) and outcome measures were fastest time or number of incorrect steps for all tests. Of the 13 timed walk tests (three forward tandem, eight backward tandem and two beam balance walks), only one study[22] demonstrated improved backward tandem walk in 39 healthy older adults. Functional reach, by contrast, improved by 9% and 13% in two of nine trials with healthy participants.[21,29] Most studies used high-intensity training on resistance machines; three studies used low-intensity training with elastic tubing.[28,102,105]

2.2.3 Functional Balance

Functional balance tests (n = 7) comprised 10% of the total balance tests performed. Four of 29 studies (four tests, 57% of functional tests) showed significantly improved balance performance. Frail, mobility-limited elderly demonstrated significantly improved balance in the Berg Balance Test after high-intensity PRT using resistance machines.[30] In comparison, other studies of frail, elderly cohorts[92,98] showed no change in the Berg Balance Test after low and moderate PRT using free weights and other weighted equipment. Two of three trials using CS-PFP testing improved after training on resistance machines.[20,31] It was the power training group, in the study of Miszko et al.,[31] and not strength training group that improved in this test. Healthy older adults training at moderate intensity

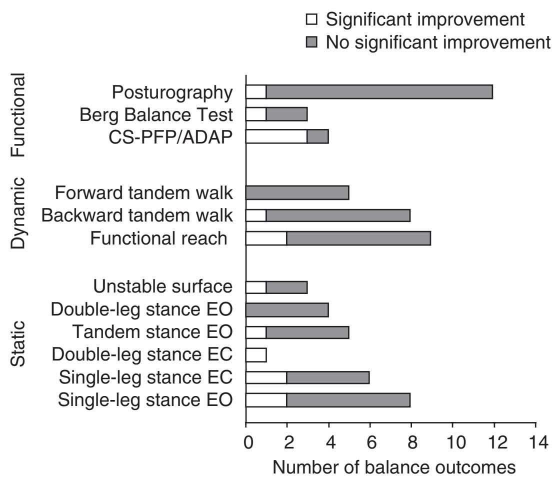

Fig. 3. Improvements in specific balance outcomes. **ADAP** = Assessment of Daily Activity Performance; **CS-PFP** = Continuous Scale-Physical Functional Performance; **EC** = eyes closed; **EO** = eyes open.

with elastic tubing and free weights improved in the balance component of the ADAP, although no statistical value was reported.[24]

2.2.4 Computerized Dynamic Posturography

Balance testing using computerized dynamic posturography comprised 8% of the total balance tests (n = 12) performed.[32,33,47] Training intensity ranged from low to high. Training equipment included resistance machines[32,33] and Therabands™.[47] All participants were healthy, and community dwelling. One of three studies (one test, 8% of posturography tests) showed significantly improved balance performance after power training at low intensity.[32]

2.2.5 Subgroup Analysis

We looked for patterns and factors that might explain the heterogeneous findings by stratifying the balance tests showing significant improvements by cohort, intensity of training, training duration, training equipment, quality of the papers and use of blinded assessors. Chi-square testing was also conducted to determine statistical difference between strata. The number of balance tests (and percentage) showing a significant improvement following training compared with the total number of tests for most factors are presented in figures 4–9. In summary, no clear trends emerged. Balance improved most in longer duration studies (figure 4). Chi-square analysis showed a significant difference between studies lasting 40–104 weeks compared with those of shorter durations (χ^2 = 6.00). Analysis of cohort

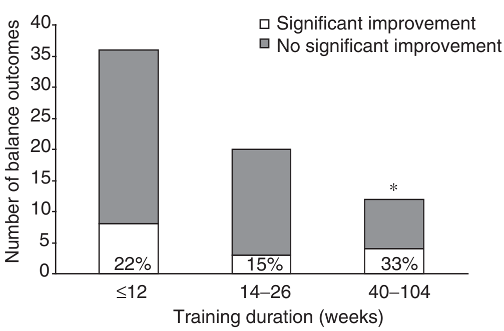

Fig. 4. Balance outcomes stratified by training duration. Studies showing significant balance improvement in training duration of: ≤12 weeks,[21,23,24,28-30,32,33] 14–26 weeks[20,25,31] and 40–104 weeks.[22,26,27] Note that some studies have more than one balance outcome. * indicates significantly different from shorter duration training periods (χ^2 = 6.00).

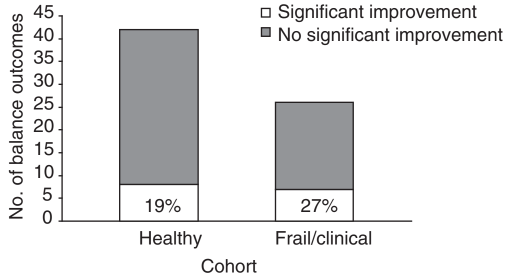

Fig. 5. Balance outcomes stratified by cohort. Studies showing significant balance improvement in: healthy cohorts[21-25,27,29,31-33] and frail/clinical cohorts.[20,26,28,30] Note that some studies have more than one balance outcome.

(figure 5), training intensity (figure 6), quality assessment (figure 7), assessor blinding (figure 8) and training equipment (figure 9) revealed no significant distinction between strata (χ^2 = 0.27–2.99). Static balance improved after low-intensity training in three poorer quality studies,[26-28] after moderate-intensity training,[23] and after high-intensity training in two better quality studies.[25,33] Dynamic balance improved with high-[21,22] and moderate-intensity training.[29] The better quality studies (PEDro score ≥6), showing significant improvements in balance performance, were predominantly studies of healthy cohorts undertaking high-intensity, short-term (10–12 weeks) training with resistance machines.

3. Discussion

This is the first systematic review to examine the efficacy of RCTs of PRT alone on balance performance in older adults. Although PRT is often stated to be beneficial for balance, this review provides evidence that PRT as an isolated intervention is not uniformly effective in improving balance performance. Only 22% of results from the balance tests examined offered support for the efficacy of PRT as a single modality to improve balance. One factor that must be considered is that balance was only one of a number of outcomes explored in all the studies reviewed, and therefore many studies may not have been optimally designed to investigate change in balance performance alone nor sufficiently powered to find such an effect.

The inconsistent effect of PRT on measures of balance may be due to: the heterogeneity of cohorts

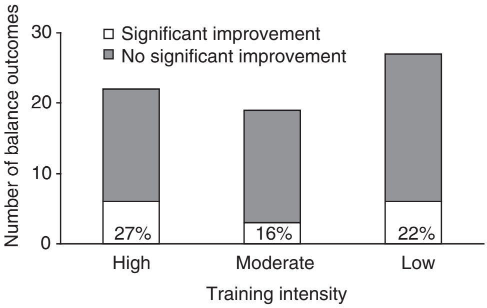

Fig. 6. Balance outcomes stratified by intensity of resistance training. Studies showing significant balance improvement in: high-intensity,[20-22,25,30,33] moderate-intensity[23,24,29] and low-intensity[26-28,31,32] resistance training. Note that some studies have more than one balance outcome.

and balance measures; a wide disparity in the conduct of balance tests; diversity of equipment used for PRT; inadequate or ineffective dose of the training programme; variability in sample size; lack of statistical power to detect between-group differences; inadequate compliance with the exercise programmes; and/or differences in overall quality of studies. The greater number of trials may have produced a learning effect in participants,[38] further confounding comparisons across studies. However, it is also possible that PRT alone is not a robust balance-enhancing intervention.

Static balance tests were the most frequently used tests, with SLS accounting for 40% of all tests, supporting the view of Wolfson et al.[33] that SLS is the most frequently used balance test in studies involving older adults, Generally, balance measured by SLS and tandem stance in the eyes-open condition, did not respond to training. The studies demonstrating significantly improved SLS and tandem stance employed stance times of 30–45 and 60 seconds, respectively. Most studies conducted the test only for 10 seconds. The authors using the FICSIT-3 tests[93,96] suggested that the lack of significant finding was because the parallel and semi-tandem stances were too easy for their cohorts. Ferrucci et al.[14] shared a similar view, finding that >45% of disabled women could maintain the tandem stance for 10 seconds. The static balance protocols using relatively short maximum test times may produce a ceiling effect because the test is too short to detect imbalance thus missing subtle balance impairments. The ceiling effect may also explain results in a cohort without overt balance impairment that performs well initially, and cannot improve further without training. The result is, thus, a negative outcome[94] and underestimation in balance adaptation.[39] A recent meta-analysis of SLS times[39] reported mean stance times in the eyes-open condition for three age groups (60–69, 70–79 and 80–99 years) as 27.0, 17.2 and 8.5 seconds, respectively suggesting that maximum times of ≤15 seconds for cohorts younger than 80 years may not detect any change in this test.

Training also provided no benefit to SLS with eyes closed. The two studies reporting improvements in this test,[23,28] however, contained methodological problems. In one study,[28] data were non-normally distributed and no indication that statistical normalization of data had been attempted prior to use of parametric analytic techniques. Nichols et al.,[23] trained 57 younger, healthy participants at moderate intensity on resistance machines. The SLS test (two practice plus three trials) was conducted over 45 seconds on each leg and then the times summed. It is possible a learning effect could have occurred with the ten trials for this test. Furthermore, one group trained progressively at equal concentric/eccentric load, the other at greater eccentric load, the progression of which was equipment-limited. The balance results of the two groups were then combined for analysis, compromising the evaluation of the effect of PRT on balance.

There is considerable variation in the reported methodology of static and dynamic tests and a lack

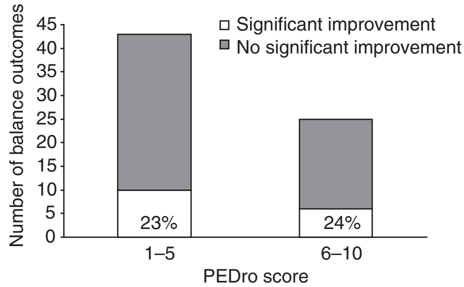

Fig. 7. Balance outcomes stratified by quality assessment. Studies showing balance improvement in: poorer quality (1–5)[20,22,23,26-29,31] and better quality (6–10)[21,24,25,30,32,33] Physiotherapy Evidence Database (PEDro) scores. Note that some studies have more than one balance outcome.

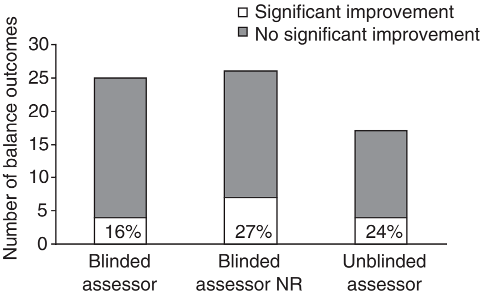

Fig. 8. Balance tests stratified by assessor concealment. Significant balance improvement in: studies using blinded assessor,[21,24,25,33] studies not reporting use of blinded assessor[20,22,23,26,28-30,101] and studies not using blinded assessor.[27,31,32] Note that some studies have more than one balance outcome. **NR** = not reported.

of specific description in some studies. Standardization of methodology and better reporting of procedures will ensure greater comparability of results in future studies. Because of the multifactorial causes of balance impairment[18] using several types of balance tests to develop a balance 'profile' in future studies may impart a more robust determination of effect following intervention.

We inspected the 15 (seven static, three dynamic, four functional and one posturography) balance tests demonstrating significant improvements for the presence of trends. No single balance test demonstrated prominence over the other tests. However, 57% of the functional tests exhibited significant improvements, greater than the other balance types. This could be explained by the Berg Balance, CS-PFP and ADAP tests having well defined test protocols, using quantitative scales and having strong intra- and inter-rater reliability.[10,42] One factor to take into consideration is that in one study using the CS-PFP,[31] a 39% withdrawal rate in the power training group compared with an overall 22% study withdrawal may compromise the validity of this significant finding.

When we stratified the balance tests by cohort, the balance tests performed by the frail/clinical group showed more improved outcomes (27%) than the healthy group. This is not an unexpected outcome as those individuals with some co-morbidities (depending on their nature) and/or mobility/functional limitations may be more likely to respond to PRT and show greater relative improvements than healthy cohorts. It is plausible that fewer improvements were evident in tests conducted in the healthy populations because of a ceiling effect. The balance tests selected may not have been the most appropriate ones chosen to adequately challenge postural stability in minimally impaired individuals.

We also stratified dose-response characteristics to examine whether intensity and/or duration may affect balance outcomes. In studies of high-intensity training, significant balance gains were observed in six tests, equally distributed between static, dynamic and functional balance types. These improvements in balance performance were predominantly observed in higher quality studies (four of six) of healthy cohorts undertaking high-intensity, short-term (10–12 weeks) training, using resistance machines. A standardized and quantifiable dose of training can be achieved by training on resistance machines. High-intensity training may best deliver the stimulus required to increase muscle strength and to elicit neuromuscular benefits to enhance balance. Recent evidence has shown that muscle activation capacity and calf muscle-tendon mechanical properties relevant to contractile force production are highly correlated to more demanding balance tasks (SLS and tandem stance).[106] Studies are needed to further examine whether high-intensity PRT can amplify the muscle-tendon properties, and determine which dose will provide optimal gains in balance.

In studies of low-intensity training, significant balance gains were observed in six tests, four of

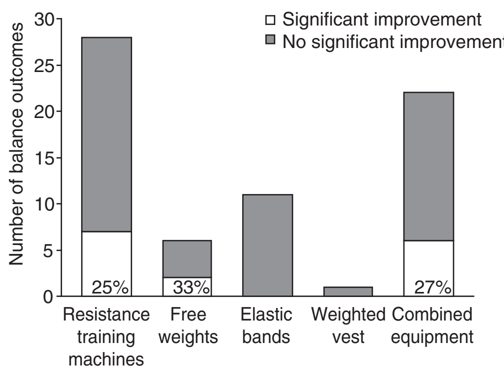

Fig. 9. Balance test stratified by training equipment. Studies showing significant balance improvement using: resistance training machines,[22-25,29,30,32]; free weights[21,26] and combined equipment.[20,24,27,29,33] Note that some studies have more than one balance outcome.

which were static balance measures. These improvements in balance performance were predominantly observed in lower-quality studies (five of six) of various cohorts undertaking low-intensity training with free weights, Therabands™, and other equipment. The data suggest that if low-intensity training improves balance, it may preferentially improve static balance.

Balance tests were more likely to improve in longer-term than shorter-term studies (33% vs 22%), suggesting a threshold of total training duration or volume may be required to elicit gains. However, there were relatively few long-term studies in this review and statistical analysis of data just reached a level of significance.

The lack of a pronounced effect of PRT on balance (in 78% of tests) in this review may also imply that strength is not the major underlying mechanism for poor balance, and that other limiting factors influence postural stability. Balance control is determined by an integrated network of vestibular, visual, cognitive, somatosensory and motor systems. A 'unique combination of constraints' for each elderly individual will govern their postural orientation and equilibrium.[107] In response to postural challenge, an individual will slow the centre of mass by generating muscle torque at the ankle or hip or by taking a step. The selection of one of these three strategies will depend on the base of support, location of centre of mass, speed of perturbation and surface characteristics.[107] The key muscle groups used to effect these balance strategies are ankle dorsiflexors and plantarflexors, knee extensors and flexors and hip abductor and adductors. Aging dampens reaction time and muscle strength, impairing, in some people, the ability to control a fall. In older adults, lateral stability is the key contributor to maintaining balance control.[108] The muscle torque required to maintain balance may be greater than the force that can be generated by older muscle. Specifically, weakness of hip abductors has been shown to compromise the ability to maintain lateral stability during stepping and thus maintain balance.[109,110] This may have serious implications for those at risk, such as fallers who have demonstrated greater lateral sway than non-fallers.[111] Furthermore, hip fractures, the most serious fractures resulting from falls, may be partly attributed to deficits in lateral stability, resulting in a fall onto the greater trochanter specifically.[112,113] Training of hip musculature has, for the most part, not been carried out. In the studies reviewed, eight studies[21,24,26,28,94,100,102,104] (28%) trained hip abductor muscles, four of which showed improved balance.[21,24,26,28] Rather than prescribing universal whole-body or lower-extremity strength training, it may be prudent to focus on specific muscles critical to balance such as hip abductors and adductors, knee flexors and extensors and ankle plantarflexors and dorsiflexors.

Muscle power generation may also be a limiting factor in the control of balance. The age-related decline in neural processing can diminish the ability for rapid force development necessary to respond to postural challenge.[108,109,114] Healthy, community-dwelling, older women have recorded a 40% decline in the rate of force development in hip abduction and abduction compared with younger women, which may have a more marked effect on postural challenges than muscle strength.[109] Chang and colleagues[115] have documented the relationship between rate of force development of hip abductors and mediolateral stability in 30 community-dwelling older adults. Hip abductor rate of force development was a stronger predictor of compensatory stepping than centre of pressure displacement (sway). We have previously shown that muscle power is related to balance in non-frail older adults[19] and obese, older adults with type 2 diabetes.[116] In this review, 18% of studies (n = 4)[11,31,32,101] used power training, two of which showed improved balance.[31,32]

Because of the association between muscle weakness and falls or poor balance, most studies have focused on one adaptation to PRT, specifically the increase in muscle strength, as a mechanism for the improvement to balance control. That is, PRT increases muscle strength thereby increasing the force that muscles can generate in response to a loss of balance. Yet few studies in this review have tested this assumption by examining the relationship between the change in strength and the change in balance. In the two studies that have examined this relationship in healthy older adults, gains in strength were not associated with improved balance.[32,33] Alternatively, other adaptations provided by PRT (e.g. increased neural drive to agonist muscles,[114] increased motor unit recruitment and activation,[114] improved cognition[117-119] decreased depression,[120] reduced antagonist muscle co-contraction,[114] enhanced stability of muscle co-ordination[121] and improved force control[114]) could also explain the efficacy of PRT on balance.

A potential limitation of this review is that we did not use abstracts, unpublished studies or thesis dissertations and a search/publication bias may have been introduced. We used only RCTs and did not include some well conducted dose-response studies that had fulfilled the criteria in all ways except that they lacked a randomized control group. This may have introduced a detection bias, where valid results have not been reported.

3.1 Implications for Research

Future directions to improve the empirical knowledge in this discipline would be to:

- employ robust RCT study designs;
- standardize the methodology of static and dynamic balance tests in order to make comparisons between studies more meaningful;
- assess a balance profile of the individual with a number of different tests to pinpoint weaknesses or deficits to individualize the intervention and optimize outcome;
- assess balance when delivering an unpredictable perturbation;
- conduct more studies using preclinical and frail populations and cohorts with multiple co-morbidities;
- investigate dose-response effects of PRT on balance performance;
- examine the effect of various intensities of training on static balance and to further define neuromuscular and other mechanisms that may underlie changes in balance with PRT.

More robust studies of longer duration are needed to confirm the preliminary evidence that balance improves when training takes place over longer periods. In addition, future studies should investigate the potential benefits of using resistance training to target muscle groups and to elicit neural adaptations specific to balance control. To this end, the merits of hip abductor and adductors strengthening as part of any exercise regimen aimed at improving lateral balance and reducing falls, and use of the less conventional power training, should be considered.

4. Conclusion

The results of this review suggest that PRT as an isolated intervention has not to date been consistently shown to improve balance performance in older adults. However, we found a wide disparity in the methodology of the static and dynamic outcomes assessed in these trials. Better reporting of the procedures in studies and regulation of the balance tests is recommended. Clinically relevant outcomes may have been overlooked due to the presence of type II errors in some studies. Nevertheless, before PRT is discounted as an efficacious intervention in the treatment of postural instability, future studies should examine possible relationships between accompanying adaptations to PRT and balance improvements that may provide further insights to the mechanism(s) by which PRT affects balance. At this time, recommendation to use PRT as an isolated intervention strategy for balance enhancement in an elderly cohort cannot be made based on the limited evidence presented in currently published data.

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