Ageing, Muscle Power, and Physical Function:

A Systematic Review and Implications for Pragmatic Training Interventions

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Short Title: Muscle power, physical function, and training implications for older people

Key Points

- Muscle power and maximal angular velocity of movement are key determinants of functional performance.
- Power training should be considered an alternative to, or progression from, traditional resistance training, and may produce greater improvements in muscle power and functional performance.

Abstract

Background: The physiological impairments most strongly associated with functional performance in older people are logically the most efficient therapeutic targets for exercise training interventions aimed at improving function and maintaining independence in later life.

Objectives: The objectives of this review were to: (i) systematically review the relationship between muscle power and functional performance in older people; (ii) systematically review the effect of power training interventions on functional performance in older people; and (iii) identify components of successful power training interventions relevant to pragmatic trials by scoping the literature.

Methods: Our approach involved three stages. Firstly, we systematically reviewed evidence on the relationship between muscle power, muscle strength, and functional performance. Secondly, we systematically reviewed power training intervention studies that included both muscle power and at least one index of functional performance as outcome measures. Finally, taking a strong pragmatic perspective we conducted a scoping review of the power training evidence to identify the successful components of training interventions needed to provide a minimally effective training dose to improve physical function.

Results: Evidence from 44 studies revealed a positive association between muscle power and indices of physical function and that muscle power is a marginally superior predictor of functional performance than muscle strength. Nine studies revealed maximal angular velocity of movement, an important component of muscle power, to be positively associated with functional performance and a better predictor of functional performance than muscle strength. We revealed 31 power training studies, characterised by small sample sizes and incomplete reporting of interventions, resulting in less than one-in-five studies judged as having a low risk of bias. Thirteen studies compared traditional resistance training to power training, with ten studies reporting the superiority of power training for either muscle power or functional performance. Further studies demonstrated the efficacy of various methods of resistance and functional task power training on muscle power and functional performance including low load power training and low volume interventions.

Conclusions: Maximal intended movement velocity, low training load, simple training methods, low volume training, and low frequency training were revealed as components offering potential for the development of a pragmatic intervention. Additionally, the research area is dominated by short-term interventions producing short-term gains with little consideration of the long-term maintenance of functional performance. We believe the area would benefit from larger and higher quality studies and a consideration of optimal long-term strategies to develop and maintain muscle power and physical function over years rather than weeks.

1.0 Background to the Problem

In this review, we consider the physiological impairments most strongly associated with functional performance in older people as the most efficient therapeutic targets for exercise training interventions aimed at improving function and maintaining independence in later life. Impairments in muscle strength and power are known to have robust associations with mobility limitations, and resistance training is effective at improving these impairments and mobility performance. Interventions aimed at preventing mobility decline are increasingly multi-modal and may involve resistance exercise, aerobic exercise, nutrition, and psychosocial components[1]. Determining the most effective, practical, and efficient resistance training dose (e.g. type of training, intensity, volume, frequency, and duration) will help optimize this component. Pragmatic trials, in particular, may benefit from this approach due to their implementation in real-life settings where resources are likely to be limited.

Current resistance training guidelines for older adults by the American College of Sports Medicine (ACSM)[2, 3] may not represent the most targeted and efficient means of improving the physiological impairments most closely associated with functional performance. The ACSM recommend a training frequency of 2-4 days per week, a training volume of 1-3 sets of 8-12 repetitions across 6-12 exercises targeting the major muscle groups, and a loading of 60-80% of 1 repetition maximum (1 RM)[2, 3]. Whilst such an exercise prescription has been demonstrated as effective at significantly increasing muscle strength, muscle size, and functional performance in older people [4, 5], the logistical and resource constraints (i.e. requirements for specialist equipment, specialist facilities, supervision, time, cost, and travel) limit the widespread adoption of the ACSM model as a pragmatic intervention.

Muscle power training has emerged as an alternative modality to the type of traditional resistance training advocated by the ACSM model and aims to improve impairments in muscle power. Whilst acknowledging the contribution of other physiological impairments (e.g. muscle mass, muscle composition, muscle architecture, muscle quality, neuromuscular activation etc.) to functional limitations, the aim of the current review is to focus on the relationship between muscle power impairments and functional performance and the effect of power training interventions on power and functional performance in older people.

1.1 Objectives

The three objectives of this review were to: (i) systematically review the relationship between muscle power and functional performance in older people; (ii) systematically review the effect of power training interventions on functional performance in older people; and (iii) identify components of successful power training interventions relevant to pragmatic trials by scoping the literature.

1.2 Search methods

Studies were included in the first systematic review if: (a) participants were ≥65 years; and (b) the study quantified the relationship between at least one muscle power or maximal angular velocity outcome measure and one physical function outcome measure. Studies were included in the second systematic review if: a) participants were ≥65 years; (b) the study evaluated a power training intervention with at least one muscle power or maximal angular velocity outcome measure and one physical function outcome measure; and (c) had a clearly identified and age-matched comparative training group or non-exercising control group. Studies were excluded from both searches if they were not written in English. For both reviews, the MEDLINE database was searched over the period 1946 to November week 3 2015. The two search strategies are provided in Electronic Supplementary Material Appendix S1. Additional sources were gained by screening the reference lists of all included studies. Data were extracted independently by the lead author using a custom data extraction form for each search. Figures 1 and 2 illustrate the PRISMA flow diagrams for the two searches.[6] Power training studies from the second search were evaluated independently by the lead author with The Cochrane Collaboration's tool for assessing risk of bias on two domains (i.e. random sequence generation and blinding of outcome assessment)[7].

**** Insert Figure 1 Here ****

**** Insert Figure 2 Here ****

The methods of the final scoping review were based on the iterative scoping methodology described by Levac et al.[8] to identify gaps in knowledge and generate specific questions to search for evidence. Our interest was in determining the most effective and practical resistance training components relevant to pragmatic trials. We asked, what is the most effective type of training (e.g. traditional low velocity resistance training or high velocity power training), the optimal training intensity/load (e.g. low or high), the minimum training volume (i.e. sets and number of exercises), the minimum training frequency (i.e. days per week), and the optimal duration of training (i.e. weeks) required for improving physical function in older people. We reviewed the studies generated above in the second systematic search, searched their reference lists, and searched the MEDLINE database over the period 1946 to November week 3 2015.

2.0 Muscle Function and Physical Function: The Importance of Strength, Power and Velocity

Research over the last four decades has systematically identified the physiological impairments most strongly associated with functional performance. Whilst early studies revealed the importance of muscle strength for functional performance [9-12], more recent studies have revealed the importance of muscle power[13]. The performance of functional tasks in older people is characterised by the combination of varied proportions of maximum strength (i.e. relative effort) produced dynamically across a range of angular velocities. Relative effort varies across agonist muscle groups involved in the task[14]. For example, relative effort estimations during walking indicate the hip (≈27%) and knee (≈30%) extensors operate at low levels, whereas the ankle plantar flexors operate at near maximal effort[14]. The knee extensors demonstrate greater activation during stair ascent, stair descent, and chair rise with relative effort estimated as (mean ± SD) 78 ± 20%, 88 ± 43%, and 80 ± 34% of maximum strength, respectively[15]. Peak knee angular velocities during these activities were measured at 141 ± 25°$\cdot s^{-1}$, 114 ± 18°$\cdot s^{-1}$, and 138 ± 25°$\cdot s^{-1}$, respectively[15]. During maximal velocity stair ascent, mean and peak velocities have been measured at 134 ± 33°$\cdot s^{-1}$ and 230 ± 47°$\cdot s^{-1}$ for the knee extensors and 95 ± 23°$\cdot s^{-1}$ and 152 ± 321°$\cdot s^{-1}$ for the ankle plantar flexors[16]. Similarly, during sit-to-stand movements performed slowly and quickly at various seat heights, peak angular velocities are in the range 122-186°$\cdot s^{-1}$ and 141-224°$\cdot s^{-1}$ for knee and hip extension, respectively[15, 17, 18]. Thus, functional performance relies on the product of muscle force and velocity (i.e. muscle power), and the extent to which the age-related loss of muscle power, compromises the ability of the primary agonist muscle group involved in the task[14, 19].

2.1 Muscle Power and Physical Function

Our systematic search revealed 44 studies investigating the relationships between indices of muscle power and physical function[16, 20-62]. Bassey et al. in 1992[20] were the first to describe significant positive linear relationships between knee extensor power and indices of functional performance (i.e. speed of chair rise, stair climb, and walking) in a small sample of very old (80-99 y) chronic care hospital residents.

A common approach has been to investigate whether muscle power explains more of the variance in functional performance than muscle strength. We identified 16 studies that either directly adopted this approach or provided data enabling a comparison[16, 21, 23, 25, 27-30, 32, 35, 42, 46, 52, 60-62]. This data establishes both muscle strength and power as important predictors of physical function in older adults, and also provides evidence that muscle power is a marginally better predictor of functional performance than strength (see Table 1)[16, 21, 23, 25, 27-30, 32, 35, 42, 46]. When viewed alongside evidence demonstrating the longitudinal decline in muscle power occurring at an earlier age and/or at a greater rate than muscle strength[21, 63-71], it is reasonable to argue in favour of muscle power being the primary therapeutic target for resistance training interventions aimed at enhancing physical function and preserving independence in later life[13, 48, 72].

Twelve of the 16 studies in Table 1 provide evidence in favour of muscle power explaining marginally greater variance in functional performance than muscle strength. Bean et al.[29] reported that leg extensor power explained 12-45% of the variance in a range of functional performance indices and accounted for 2-8% more variance than leg extensor 1RM strength. Using forward step-wise multiple regression analysis, Foldvari et al.[25] reported that leg press power and habitual physical activity were the only two variables from a range of physiological (e.g. 1RM strength, muscle endurance, and maximal oxygen uptake), neuropsychological, and health status variables that contributed independently to explaining 40% of the variance in self-reported functional status. Lower limb muscle power has explained over one-third [32, 33, 35, 40, 42, 46, 51, 58] and over one-half [16, 20, 24, 27, 30, 37] of the variance in functional performance.

The evidence base has also highlighted the curvilinear nature of the relationship between power and functional performance[29, 35, 42]. Cuoco et al.[35] reported that leg press power explained more of the variance in functional indices when quadratic curvilinear regression models were applied (18-50%) rather than linear models (12-35%). Similarly, Marsh et al.[42] reported data for 655 men and women and observed that leg press power explained 35% of the variance in 400 m walking time with a cubic model versus 31% with a linear model. These data are consistent with the curvilinear relationships observed between muscle strength and functional performance [73, 74]. Curvilinear relationships support the concept of functional thresholds for muscle strength and power, whereby a dramatic loss of physical function occurs with declining strength or power below the threshold, and increasing strength or power above the threshold produces modest improvements or a plateau in functional performance albeit with an increasing muscle strength/power reserve or safety margin [20, 24, 73, 75]. Whilst acknowledging the potential utility of a threshold from a clinical diagnostic perspective, Marsh et al.[42] were unable to identify such a threshold in their data and stated that a continuous curvilinear relationship exists between muscle power and physical function. On the basis of such a relationship, low functional groups (e.g. pre-frail, frail) would likely demonstrate the greatest functional benefits for a given improvement in muscle power in response to a training intervention. On the other hand, high functioning groups demonstrating successful ageing, are less likely to exhibit dramatic functional improvements for a given change in muscle power.

**** Insert Table 1 Here ****

2.2 Maximal Angular Velocity of Movement and Physical Function

Since muscle power is the product of force and velocity, several researchers have investigated the relative importance of maximal force and maximal movement velocity as determinants of functional performance. Nine of the 44 studies examined these relationships, with eight studies comparing force and velocity, and one study investigating velocity only (see Table 2)[16, 39, 47-50, 54, 55, 57]. This emerging evidence demonstrates that velocity is significantly associated with functional performance, with the eight comparative studies also suggesting that maximal velocity is an equal or better predictor of functional performance than maximal force.

For example, Van Roie et al.[54] reported that maximal unloaded knee extension velocity (R^2 = 46%) demonstrated the highest correlation with physical function in comparison with isometric strength (R^2 = 32%) and a range of dynamic (R^2 = 10-37%) knee extension strength measures in a sample of 123 institutionalized older women. Pojednic et al.[57] reported that maximal knee extension velocity during a 40% 1RM leg press in 25 mobility-limited older adults contributed significantly to the 59% and 29% explained variance in repeated chair rise time and stair climb time, respectively; whereas isometric MVC did not significantly contribute to the explained variance in either activity. Clémençon et al.[49] measured the load-velocity relationship during knee extension in 39 older (72-96 y) women who were retirement home residents and determined peak power, velocity at peak power (termed optimal velocity), and torque at peak power (termed optimal torque). Optimal velocity (103 ± 69°·s^{-1}) explained substantial variance in 5 x chair rise time (47%), 6 step stair climb time (90%), and 6 m maximal walking speed (49%), and the explained variance was not increased by the addition of optimal torque into the regression model. The studies in Table 2 summarise the emerging evidence that maximal joint angular velocity is an important determinant of functional performance.

A measure of maximal angular velocity potentially represents a simple clinical tool to serve as an early warning of future disability. Van Roie et al.[54] reported that knee extensor isometric strength and maximal unloaded velocity were significantly different between older people categorised by their modified physical performance test score as not frail (1.70 ± 0.40 Nm·kg^{-1}; 365 ± 43°·s^{-1}), mildly frail (1.31 ± 0.29 Nm·kg^{-1}; 318 ± 48°·s^{-1}), and moderately frail (1.01 ± 0.28 Nm·kg^{-1}; 242 ± 65°·s^{-1}). Whilst the value of measuring strength is acknowledged, a measurement of angular velocity has the practical advantage of not requiring a dynamometer. The feasibility of such a measure has been demonstrated by Arai et al.[47, 55] utilising a limb mounted gyroscope to gain measurements of maximal angular velocity during standing plantar flexion (≈360°·s^{-1}) and seated knee extension (≈430°·s^{-1}) in healthy older people. Van Roie et al.[54] reported the sensitivity and specificity analysis for a knee extensor velocity threshold of 350°·s^{-1}, which correctly identified 77% of participants as mildly frail with values below the threshold and 71% correctly identified as not frail with values above the threshold. The predictive and discriminative value of maximal angular velocity is likely due to the reflection of underlying neuromuscular adaptations occurring early in the ageing process and resulting in a slowing of maximal muscle shortening velocity. In a cross-sectional study of 335 men aged 23-88 years, Kostka detected a significant reduction in optimal velocity during sprint cycling already occurring at 30-40 y, which preceded the reductions in peak power (40-50 y) and quadriceps muscle mass (60-70 y)[66]. Pearson et al. reported that optimal velocity during sprint cycling is positively associated with the percentage of fast myosin heavy chain isoforms in vastus lateralis in young and older men, with older men having a significantly lower percentage (25.6 ± 7.1% vs. 52.1 ± 6.4%) and lower optimal velocity (90 ± 6 vs. 120 ± 3 rpm)[76]. The emerging evidence on the important role of maximal velocity as a determinant of functional performance suggests that training interventions should seek to optimize both strength and velocity.

**** Insert Table 2 Here ****

2.3 Muscle Power Asymmetry and Physical Function

The prevalence of lower limb power asymmetry, defined as the difference in limb power as a percentage of the strongest limb, increases with age[20, 38, 45, 52]. Bassey et al. in 1992[20] were the first to observe the prevalence of bilateral power asymmetry (i.e. >10% contralateral difference) in two-thirds of their sample of very old (80-99 y) chronic care hospital residents, whilst Portegijs et al.[38] observed mean leg press power asymmetry of 15 ± 9% in a large sample (n=419) of healthy older women aged 63-75 y. The prevalence is higher in samples with reduced functional status and with a history of falls. Carabello et al.[52] observed significantly greater leg power asymmetry in mobility limited older adults (≈20%) versus healthy older adults (≈12%) and healthy middle-aged adults (≈10%). In a sample of women aged over 65 y with (n=20) and without (n=15) a history of falls, Skelton et al.[77] reported the prevalence of leg power asymmetry (i.e. >10%) as 60% in the fallers versus 13% in the non-fallers.

Asymmetry alone may not be associated with functional performance [52] or falls risk[45], but rather the interaction with low muscle power appears the important feature[38, 77]. Portegijs et al.[38] reported that maximal walking speed was poorest in those individuals belonging to a sub-group (n=73) with leg power below the median and asymmetry in the highest tertile. Furthermore, 12% of their total sample were unable to maintain tandem balance for 20 s and these participants displayed significantly less power in both limbs and a significantly greater asymmetry of 18.6% versus 14.3% in the wider sample[38]. These physiological impairments appear to manifest in a subsequent increased incidence of falls. During a 1 year prospective study of injurious falls, the tertile with the largest asymmetry (n=146) had a 34% incidence of at least one injurious fall and 12% for recurrent injurious falls[78]. The incidence in the remainder of the sample (n=257) with symmetrical leg power was 24% and 5%, producing crude odds ratios of 1.7 and 2.4, for one injurious fall and recurrent injurious falls, respectively[78].

Lower limb power and asymmetry also appear important determinants of functional performance recovery in hip fracture patients[22]. Lamb et al.[22] identified leg press power of the fractured leg, measured one week after surgical fixation of proximal femoral fracture, as the strongest predictor of walking speed and stair climb time at this time point. Portegijs et al.[51] reported that power of the non-fractured leg at week 1 post-surgery was the strongest predictor of comfortable walking speed at this time-point and also at 13 weeks post-surgery. Portegijs et al.[51] defined leg power asymmetry as the fractured leg power as a percentage of the sum of both legs, with 50% indicating perfect symmetry and lower values indicating poorer power in the fractured leg. They reported mean asymmetry of 28.5 ± 10.2% at week 1 improving to 40.4 ± 8.6% at week 13 with lower values associated with poorer stair climb speed at each time point. Additionally, the improvement in asymmetry was associated with the improvement in stair climb speed from week 1 to 13[51].

Whilst leg power asymmetry is a subtle presence in the healthy and mobility limited older population, it is more obvious in populations at risk of falling. Whether reducing asymmetry with training interventions improves physical function and reduces risk of falls remains to be established.

3.0 Training Interventions for Power & Functional Performance

3.1 Quality of Studies

Our systematic search revealed 31 studies reporting the effect of power training interventions on both muscle power and functional performance (see Tables 3-5)[79-109]. Study sample sizes were generally small, with two-thirds having <50 participants, one-fifth 50-100 participants, and only 10% involving ≥100 participants. Only 35% of studies were judged to have 'low risk' of bias for sequence generation and 16% 'low risk' of bias for blinding of outcome assessors, resulting in 16% of studies judged as 'low risk' on both domains. Insufficient information was the main quality concern resulting in 'unclear' judgements for 45% and 74% of studies for sequence generation and blinding, respectively. This lack of transparency also affected judgement on the participant's acceptability of the intervention (generally not reported), the occurrence of adverse events (reported inconsistently), and the participant's adherence to the intervention (reported inconsistently).

3.2 Definition of Power Training

In traditional resistance training (TRT) the lifting movements are performed at low velocity with the concentric and eccentric phases completed in 2-3 seconds each e.g. 30-45°·s^{-1} for a 90° range of motion[2, 3]. The studies reviewed in Tables 3-5 involved power training (PT) where participants are instructed to perform the concentric phase "as fast as possible" and the eccentric phase normally. Therefore, PT is distinguished from TRT by the *intention* to move with maximal velocity[94]. The *actual* movement velocity during PT will be determined by the load (i.e. % 1RM) due to the force-velocity relationship of skeletal muscle. The studies summarised in Tables 3-5 have employed the maximal intended movement velocity principle to create PT interventions with resistance machines, free weights, body weight, weighted vests, elastic band resistance, and cycling against resistance. Power training with external resistance may involve loads consistent with TRT (i.e. 50-80% 1RM) or may focus on lighter loads (e.g. 20-40% 1RM) that maximise actual movement velocity. Power training may represent the whole training intervention or as one element in a structured periodized training programme involving TRT or in a multicomponent intervention involving other methods such as functional task training. The 13 studies in Table 3 directly compared PT versus TRT, the three studies in Table 4 compared PT at different loads, and the 15 studies in Table 5 represent a variety of PT interventions, with all studies evaluated by their effectiveness on muscle power and functional performance.

3.3 Sampling and Training Content

Training interventions have involved samples ranging from healthy, independently living older adults to the institutionalized frail oldest old (i.e. >90 y). A small number of studies have involved participants following orthopaedic surgery or with chronic musculoskeletal conditions. Of these, one study involved participants in the long-term stage of rehabilitation following proximal femoral fracture[92], and one study involved participants with knee osteoarthritis[98]. One further study involved community dwelling older participants with Parkinson's disease[109]. Training volume ranged from 1-6 sets, 4-20 repetitions, and 1-11 exercises at intensities ranging from 20-80% 1RM. Training session duration ranged from 10-90 minutes with all sessions supervised. Training duration ranged from 6-52 weeks (majority 8-16 weeks) with a training frequency of 2-3 days a week.

3.4 Effectiveness on Muscle Power

A common empirical approach has been to compare the effectiveness of PT versus TRT on muscle power and physical function. Two recent meta-analyses have reviewed data from studies adopting this approach[110, 111]. In reviewing four studies comparing PT versus TRT on muscle power[82, 89, 90, 112], Steib et al.[110] reported a standardised mean difference (SMD) of 1.66 (95% confidence interval 0.08 to 3.24) in favour of PT. Steib et al.[110] considered the level of evidence as 'moderate' based on the grading method of van Tulder et al.[113] (i.e. consistent findings among multiple low-quality randomised control trial and/or controlled clinical trial and/or one high-quality randomised control trial). In reviewing seven studies[81, 89-91, 93, 114, 115], Tschopp et al.[111] reported a SMD of 0.42 (95% CI -0.02 to 0.85) in favour of PT. Tschopp et al.[111] interpreted the data as 'weak' evidence for a small effect in favour of PT due to mainly small studies producing wide confidence intervals and preventing the exclusion of a trivial difference. The Tschopp et al.[3] meta-analysis erroneously included the study of Macaluso et al.[65] as comparing PT to PRT. Macaluso et al.[65] stated that all participants were required to pedal as fast as possible and therefore their three groups all undertook PT. Their study was an investigation of different PT loads rather than PT versus TRT (see section 3.7). We identified seven further studies comparing PT to TRT not included in the two meta-analyses, including six subsequently published studies[83, 96, 98, 100, 104, 105, 108], which lend support to the superiority of PT over TRT for improving muscle power. Four of the seven studies reported significantly greater gains in lower limb muscle power following PT versus TRT[83, 98, 100, 108], two studies reported equivalent gains in lower limb power[104, 105], with one reporting greater gains in upper limb power following PT[105], and one study reported no change in power with either PT or TRT[96]. Table 3 provides a summary of 13 studies comparing the effect of PT versus TRT on muscle power and functional performance. Nine of the 13 studies support PT as a more effective method of improving muscle power than TRT.

3.5 Effectiveness on Maximal Movement Velocity

Only seven of the 31 studies reviewed employed maximal movement velocity as an outcome measure[79, 81, 93, 95, 98, 106, 109]. The evidence suggests that PT does increase maximal velocity when tested at the same absolute load (i.e. lower %1RM post-training)[79, 81, 95] and at the same relative load (i.e. higher absolute load post-training)[93, 98, 106, 109]. Additional evidence suggests that TRT also improves maximal velocity[116-118]. At present, there is insufficient evidence to judge the most effective form of training (i.e. PT vs TRT) or loading regime (i.e. low vs high %1RM) to improve maximal velocity.

3.6 Effectiveness on Functional Performance

The meta-analysis by Tschopp et al.[111] reported data on seven studies[81, 82, 84, 89, 90, 93, 94] comparing PT versus TRT on indices of functional performance. They reported a SMD after training of 0.32 (95% CI 0.06 to 0.57) in favour of PT, representing a small effect size, and a small advantage of PT over TRT for functional outcomes. The meta-analysis by Steib et al.[110] comparing PT to TRT included data from only one to three studies[89, 90, 119] and reported SMDs of 1.74 for chair rise (95% CI 0.39 to 3.10) in favour of PT, 1.27 for stair climbing (95% CI -0.06 to 2.60) in favour of PT, -0.62 for walking speed (95% CI -1.85 to 0.62) indicating no difference, and 0.03 for timed up and go (95% CI -0.85 to 0.91) indicating no difference. The authors interpreted the data as moderate level evidence supporting PT over TRT for improving chair rising and stair climbing and limited evidence for walking speed and timed up and go[110].

We identified seven additional studies comparing PT to TRT which lend partial support to the conclusion of a small advantage of PT over TRT for functional outcomes [83, 96, 98, 100, 104, 105, 108]. Four studies observed equivalent improvements in functional performance[83, 96, 98, 104], Balachandran et al.[100] reported a between group difference in short physical performance battery (SPPB) score of 1.1 (95% CI -0.1 to 2.4) in favour of PT, Ramirez-Campillo et al.[105] reported significantly greater changes in timed up and go and maximum walking speed with PT, whilst Correa et al.[108] observed greater gains in 30 s sit-to-stand repetitions when PT included a plyometric lateral box jumping exercise. Overall, six of the 13 studies in Table 3 support PT as a more effective method of improving functional performance than TRT. Collectively, the evidence supports the conclusion that performing resistance exercises “as fast as possible” provides a small to moderate advantage over slow movement velocities for improving physical function.

**** Insert Table 3 Here ****

3.7 Effect of Power Training Load

Table 4 illustrates that a small number of studies have investigated the effect of PT load (i.e. %RM) on muscle power and physical function[81, 88, 106]. Collectively, these studies suggest that muscle power and physical function can be improved by PT across a range of intensities. Low load PT appears to improve muscle power and functional performance as well as higher load PT and may be superior for postural control, whereas higher loads may provide superior benefits for maximal strength and endurance. Macaluso et al.[81] observed equivalent gains in leg press power and physical function (maximal walking speed and box stepping performance) following PT training at low (40% 2RM) or high (80% 2RM) loads. Similarly, following training at either low (40% 1RM) or high (70% 1RM) load, Reid et al.[106] observed equivalent gains in lower limb strength (low 13% vs. high 19%), power (low 34% vs. high 42%) and physical function assessed by SPPB (low 1.4 vs. high 1.8 units). These authors did observe a consistent and significantly lower rating of perceived exertion (Borg 6-20 scale) during low load training on the two training exercises of leg press (low 11.5 'light' vs. high 13.4 'somewhat hard') and knee extension (low 13.3 'somewhat hard' vs. high 14.8 'hard/heavy')[106]. Participants therefore perceived low load PT as less effortful than the higher load intervention and the authors suggested this intensity of exercise may be of particular relevance for older adults with chronic or debilitating conditions where high intensity exercise may be contraindicated or poorly tolerated[106]. Orr et al.[88] observed that balance performance improved to a significantly greater extent following PT with low loads (10.8% at 20% 1RM), versus moderate (2.1% at 50% 1RM) or high (0.3% at 80% 1RM) loads. Whilst the improvement in power was equivalent amongst the loading groups (low 14%, moderate 15%, high 14%), significant differences were observed between groups in a dose-response manner for strength (low 13%, moderate 16%, high 20%) and endurance (low 82%, moderate 103%, high 185%)[88]. Further studies should investigate whether PT with a variety of loads, rather than a single load, produces greater improvements in power and physical function.

**** Insert Table 4 Here ****

3.8 Changes in Power versus Changes in Physical Function

Only five of the 31 training studies addressed the important issue of determining to what extent changes in physiological parameters explain changes in functional performance[80, 82, 83, 88, 91]. Whilst two studies found no statistically significant relationships, the remaining three studies found that changes in physiological parameters explained 7-30% of the change in physical function. Hruda et al.[80] reported that changes in knee extension power explained 22% of the variation in timed up and go performance and 18% in 6 m maximal walking speed. Baseline maximal angular velocity of movement has also emerged as a significant determinant of changes in functional performance[88, 93]. In the study of Bean et al.[93], 37% of participants (n=68 out of 138) undertaking PT (n=31) and TRT (n=37) were categorized as having a velocity impairment at baseline based on maximal velocity produced during leg press and triceps press exercise at 70% 1RM. Analysis revealed that velocity impaired participants improved their physical function (SPPB) to a greater extent (0.73 units, p = 0.05) with PT than with TRT. The change in physical function of 2.1 SPPB units for the velocity-impaired participants with PT was also greater than the 1.75 units change seen with PT for the whole sample. Further analysis of the InVEST data set revealed that change in muscle power (change in strength was not a significant predictor) was the only variable significantly associated with clinically meaningful differences in SPPB (i.e. ≥1 unit) and gait velocity (i.e. ≥ 0.1 $m \cdot s^{-1}$)[120]. These results suggest that in addition to muscle strength impairments, power and velocity impairments are important rehabilitative targets for improving functional performance in older people.

**** Insert Table 5 Here ****

4.0 Implications for Pragmatic Interventions

The data in Tables 3-5 reveal a variety of effective approaches to improving muscle power and physical function through resistance training interventions in older people. The final aim of this review is to scope this evidence base and relevant alternative evidence to highlight components of successful power training interventions relevant to pragmatic trials where implementation in real-life settings is a key challenge.

4.1 Training Velocity

Maximal muscle power and movement velocity are important physiological determinants of functional performance in older people. Training with maximal intended movement velocity represents an effective strategy to improve power and to translate strength and power training gains into functional performance. However, for power training to be considered a pragmatic intervention, the safety and efficacy of power training needs to be demonstrated outside of the supervised gym-based environment upon which the current evidence is built. Future studies employing community and home-based training environments, varying supervision levels, and pre-frail and frail populations are required before this type of training can be considered pragmatic.

4.2 Training Load

A small number of studies have compared low versus high load PT and have generally reported equivalent gains in power and functional performance. No such studies have investigated the effectiveness of a combination of loads or use of the 'optimal' load (i.e. load that elicits maximal power production)[121]. From a practical perspective, an approach involving high velocities and low loads, would be easier to administer without specialist equipment (e.g. using bodyweight, weighted vests, resistance bands, and light hand and ankle weights) and has the benefit of producing a lower perception of effort. For these reasons, power training with low loads may be a suitable intervention for implementation in populations with low exercise capacity (e.g. frailty or hip fracture). However, as stated previously, the safety and efficacy of power training in these populations remains to be established and the current evidence base precludes any strong recommendations on the most effective loading regimes in power training.

4.3 Training Methods

The majority of studies in Tables 3-5 have employed specialist resistance training equipment typically found in gym facilities under supervision of exercise professionals. Some studies have investigated the effect of simpler modalities (under supervision) with potential for use in the home such as bodyweight, elastic resistance bands, and weighted vests[80, 84-86, 93, 122, 123]. Bean et al. employed weighted vests during a 16 week intervention employing 10 task-specific movement patterns for two sets of 10-12 repetitions with the concentric action performed as quickly as possible versus a TRT programme employing free-weights serving as the control condition[93]. The increased velocity exercise specific to task (InVEST) programme produced greater gains in limb power and equivalent gains in 1RM strength, SPPB, and self-reported function, offering a viable simple alternative to TRT[93]. De Vreede et al. reported a 12 week intervention involving functional tasks performed as quickly as possible with progressive resistance through weighted vests against a TRT control intervention[86]. Comparable improvements in leg extensor power were observed with significant improvements in functional task performance observed in the functional task intervention only[86]. Similarly, Lohne-Seiler et al. improved functional performance through inventive use of functional task training[99]. The available evidence suggests that significant improvements in muscle power and physical function can be gained through simple resisted functional task exercises performed with maximal intended movement velocity. Future research should refine the most effective functional exercises and develop novel portable resistance training modalities suitable for use at home or in community settings outside of specialist facilities. A requirement for minimal supervision would increase the pragmatic value of power training and may facilitate more sustainable and longer-term interventions but such interventions have yet to be demonstrated.

4.4 Training Volume

The minimum effective number of exercises and sets of exercises within a training session are primary considerations when determining a minimum effective training dose. A minority of the 31 studies in Tables 3-5 employed low volume interventions consisting of only one[81] or two exercises[83, 91, 98, 106]. Three of the five studies were effective in improving both muscle power and physical function with either one [81] or two exercises[91, 106]. The number of sets ranged from 1-8, the number of repetitions from 8-20, frequency from 2-3 days-a-week, and duration of intervention from 12-16 weeks. The recent effective PT study by Reid et al. employed two lower limb exercises (i.e. bilateral leg press and unilateral knee extension) for 3 sets of 10 repetitions at either 40 or 70% 1RM for 2 days a week for 16 weeks in mobility limited older adults aged 70-85 y[106]. Evidence suggests that low volume interventions comprising just one or two exercises with multiple sets and a frequency of twice a week can produce significant improvements in power and physical function in mobility limited older people and clinical orthopaedic populations.

None of the 31 training studies have investigated the effectiveness of single versus multiple sets on muscle power and physical function. Scoping of the wider literature revealed that low volume TRT approaches can be effective in improving power and physical function. Capodaglio et al. reported that a TRT intervention comprising a single set of 12 repetitions at 60% 1RM on two exercises (leg press & calf press) performed twice a week for 52 weeks significantly increased leg extensor power (4-23%) and a range of functional indices (e.g. TUG 20%, 6MWT 4.6%) in community dwelling older adults aged 70-83 y.[124] A further TRT study investigated one versus three sets of seven exercises performed twice a week for 20 weeks on indices of strength, endurance, and functional performance in 28 community dwelling men and women aged 65-78 y [125]. The single set group improved 1RM strength on all seven exercises and four of seven functional tasks including multiple chair rise time, stair climb time, and 400 m walking time[125]. The three set group were superior in 1RM gains on four of the exercises and 400 m walk time [125]. The authors concluded that an intervention involving a single set of exercises is a sufficient dose to significantly improve muscle function and physical function in older people.

4.5 Training Frequency

All of the 31 training studies reviewed employed a training frequency of two or three times per week (see Tables 3-5) and this presents a considerable logistical burden for participants and service providers and may limit the widespread adoption of these training interventions. Scoping of the wider training frequency literature revealed several studies investigating the efficacy of once-a-week training versus two and three times per week in older people [126-133]. There is ample evidence supporting the effectiveness of once a week resistance training on indices of strength, body composition, and physical function[126, 127, 129, 131, 132, 134]. Whilst evidence exists suggesting once weekly training is ineffective, this was possibly a function of the low intensity nature of the training stimulus employed in these studies [128, 130]. There is also evidence to suggest that whilst once weekly training may be effective, greater gains in body composition, strength and function occur with higher frequencies[133, 134].

Foley et al.[131] reported 94 older participants preferred training frequency following a 12 week community based exercise referral programme at a frequency of once or twice a week following discharge from a day rehabilitation centre. Tellingly, 66% of participants reported once a week as their preferred frequency versus 26% preferring twice a week, and just 1% three times per week. Evidence suggest a once weekly training frequency can be effective for strength, body composition, and physical function and initial evidence points to an overwhelming preference for this frequency. The effectiveness of once weekly power training on power and functional performance has yet to be demonstrated and this warrants further investigation.

4.6 Training Duration

The duration of interventions summarised in Tables 3-5 ranged from 6-52 weeks with a mean of 16 weeks. No study has compared the effectiveness of different durations of training or the progression of power and function beyond 24 weeks. In a 16 week TRT study, Petrella et al.[117] noted that 88% of the increase in power occurred by week 8 with no significant improvements from 8 to 16 weeks. On the other hand, continuous improvements in 1RM strength, muscle hypertrophy, and stair climbing and walking endurance were observed over 2 years of twice a week TRT in 60-80 y olds[135, 136]. In real-world scenarios it is highly unlikely that two-to-three times a week training regimes will be maintained in the long-term. Scoping produced evidence of continued functional performance gains with a 12 week once-a-week low volume TRT subsequent to a 12 week twice-a-week TRT in hip fracture patients 6-9 months post-surgery[137]. Strength gains (1RM) were maintained with once weekly training over 27 weeks subsequent to 11 weeks of three times a week training[138]. Studies exploring the use of reduced training frequency and/or volume to act as a maintenance dose for muscle power and functional gains over the long-term subsequent to short-term training would appear ecologically valid but are lacking in the literature.

A number of studies have investigated the response of strength, power, and functional performance to complete cessation of training (i.e. detraining) [139-143]. No significant losses of functional gains have been reported following 6 weeks[141], 10 weeks[142], and 24 weeks[139, 140] detraining subsequent to 12, 6, and 24 weeks of training, respectively. Gains in 1RM strength do appear sensitive to detraining with significant reductions consistently observed[139-141], whereas gains in muscle power have been reported as either maintained[139, 141, 142] or significantly reduced[140] with detraining. However, both strength and power have remained significantly elevated above the pre-training baseline following 6[141] and 24 weeks[139] of detraining. It would appear that both power and functional performance gains are maintained in the short-term following training cessation but little is known of the long-term consequences. Kennis et al. [144] reported a seven year follow-up of knee-extensor strength, subsequent to 1 year of three times-a-week training. Training did not affect the age-related rate of decline in strength but the 7-11.5% improvement in strength at year 1 resulted in baseline strength being preserved for 3 extra years versus a non-training control group and a significant attenuation of isometric (-8.7% vs -16.5%) and concentric (-7.1% vs -15.1%) strength loss at 7 years follow-up[144]. Future research should focus on developing optimal long-term strategies to develop and maintain muscle power and physical function.

5.0 Conclusions and Recommendations

Along with muscle strength, muscle power is an important determinant of functional performance in older people. Improving strength, power and velocity through resistance training interventions offers potential to maintain functional performance and independence in later life. Determining the most effective training components is important in ensuring training interventions are targeted and efficient. Adopting a pragmatic approach ensures potential interventions have the practical value for application in real-life scenarios where resources are limited. The evidence base is currently dominated by gym-based interventions requiring specialist equipment for loading. The intention to move as fast as possible during training movements is a simple modification to conventional resistance training that represents an evidence-based component that we recommend be considered for inclusion when interventions are aiming to improve power and functional performance. Future research should investigate simple loading modalities suitable for application in the home to enhance independent training and longer term sustainability. Low volume (i.e. minimal exercises or sets) and low frequency (i.e. once weekly) interventions can produce significant improvements in physical function. Future studies should focus on refining and defining the minimal effective training dose by investigating the effectiveness of low versus high training volume and low versus high training frequency. The research area is dominated by short-term interventions producing short-term gains with little consideration of the long-term maintenance of functional performance or the offsetting of functional decline. The area would benefit from a consideration of optimal long-term strategies to develop and maintain muscle power and physical function over years rather than weeks. Finally, the quality of studies needs to be improved since the current evidence-base is characterised by small sample size studies and incomplete reporting of interventions, resulting in less than one-in-five studies judged as having a low risk of bias.

Compliance with Ethical Standards

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Conflicts of Interest

Christopher Byrne, Charles Faure, David Keene and Sarah Lamb declare that they have no conflicts of interest relevant to the content of this review.

References

1. Pahor M, Guralnik JM, Ambrosius WT, et al. Effect of structured physical activity on prevention of major mobility disability in older adults: the LIFE study randomized clinical trial. JAMA. 2014;311(23):2387-96.
2. Ratamess NA, Alvar BA, Evetoch TK, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41(3):687-708.
3. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Med Sci Sports Exerc. 2009;41(7):1510-30.
4. Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians. Effects on skeletal muscle. JAMA. 1990;263(22):3029-34.
5. Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med. 1994;330(25):1769-75.
6. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 2009;151(4):264-9, W64.
7. Higgins JPT GSe. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration; 2011.
8. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implement Sci. 2010;5:69.
9. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. Scand J Rehabil Med. 1980;12(4):145-54.
10. Bassey EJ, Bendall MJ, Pearson M. Muscle strength in the triceps surae and objectively measured customary walking activity in men and women over 65 years of age. Clin Sci (Lond). 1988;74(1):85-9.
11. Bendall MJ, Bassey EJ, Pearson MB. Factors affecting walking speed of elderly people. Age Ageing. 1989;18(5):327-32.
12. Hyatt RH, Whitelaw MN, Bhat A, et al. Association of muscle strength with functional status of elderly people. Age Ageing. 1990;19(5):330-6.
13. Reid KF, Fielding RA. Skeletal muscle power: a critical determinant of physical functioning in older adults. Exerc Sport Sci Rev. 2012;40(1):4-12.
14. Beijersbergen CM, Granacher U, Vandervoort AA, et al. The biomechanical mechanism of how strength and power training improves walking speed in old adults remains unknown. Ageing Res Rev. 2013;12(2):618-27.
15. Hortobagyi T, Mizelle C, Beam S, et al. Old adults perform activities of daily living near their maximal capabilities. J Gerontol A Biol Sci Med Sci. 2003;58(5):M453-60.
16. Larsen AH, Sorensen H, Puggaard L, et al. Biomechanical determinants of maximal stair climbing capacity in healthy elderly women. Scand J Med Sci Sports. 2009;19(5):678-86.
17. Schenkman M, Riley PO, Pieper C. Sit to stand from progressively lower seat heights -- alterations in angular velocity. Clin Biomech (Bristol, Avon). 1996;11(3):153-8.
18. Gross MM, Stevenson PJ, Charette SL, et al. Effect of muscle strength and movement speed on the biomechanics of rising from a chair in healthy elderly and young women. Gait Posture. 1998;8(3):175-85.
19. Kulmala JP, Korhonen MT, Kuitunen S, et al. Which muscles compromise human locomotor performance with age? J R Soc Interface. 2014;11(100):20140858.
20. Bassey EJ, Fiatarone MA, O'Neill EF, et al. Leg extensor power and functional performance in very old men and women. Clin Sci (Lond). 1992;82(3):321-7.
21. Skelton DA, Greig CA, Davies JM, et al. Strength, power and related functional ability of healthy people aged 65-89 years. Age Ageing. 1994;23(5):371-7.

22. Lamb SE, Morse RE, Evans JG. Mobility after proximal femoral fracture: the relevance of leg extensor power, postural sway and other factors. Age Ageing. 1995;24(4):308-14.
23. Earles DR, Judge JO, Gunnarsson OT. Power as a predictor of functional ability in community dwelling older persons. Med Sci Sports Exerc. 1997;29(5).
24. Rantanen T, Avela J. Leg extension power and walking speed in very old people living independently. J Gerontol A Biol Sci Med Sci. 1997;52(4):M225-31.
25. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. J Gerontol A Biol Sci Med Sci. 2000;55(4):M192-9.
26. Kozakai R, Tsuzuku S, Yabe K, et al. Age-related changes in gait velocity and leg extension power in middle-aged and elderly people. J Epidemiol. 2000;10(1 Suppl):S77-81.
27. Samson MM, Meeuwsen IB, Crowe A, et al. Relationships between physical performance measures, age, height and body weight in healthy adults. Age Ageing. 2000;29(3):235-42.
28. Suzuki T, Bean JF, Fielding RA. Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. J Am Geriatr Soc. 2001;49(9):1161-7.
29. Bean JF, Kiely DK, Herman S, et al. The relationship between leg power and physical performance in mobility-limited older people. J Am Geriatr Soc. 2002;50(3):461-7.
30. Bean JF, Kiely DK, Leveille SG, et al. The 6-minute walk test in mobility-limited elders: what is being measured? J Gerontol A Biol Sci Med Sci. 2002;57(11):M751-6.
31. Slade JM, Miszko TA, Laity JH, et al. Anaerobic power and physical function in strength-trained and non-strength-trained older adults. J Gerontol A Biol Sci Med Sci. 2002;57(3):M168-72.
32. Bean JF, Leveille SG, Kiely DK, et al. A comparison of leg power and leg strength within the InCHIANTI study: which influences mobility more? J Gerontol A Biol Sci Med Sci. 2003;58(8):728-33.
33. Lindemann U, Claus H, Stuber M, et al. Measuring power during the sit-to-stand transfer. Eur J Appl Physiol. 2003;89(5):466-70.
34. Barker K, Lamb SE, Toye F, et al. Association between radiographic joint space narrowing, function, pain and muscle power in severe osteoarthritis of the knee. Clin Rehabil. 2004;18(7):793-800.
35. Cuoco A, Callahan DM, Sayers S, et al. Impact of muscle power and force on gait speed in disabled older men and women. J Gerontol A Biol Sci Med Sci. 2004;59(11):1200-6.
36. Petrella JK, Miller LS, Cress ME. Leg extensor power, cognition, and functional performance in independent and marginally dependent older adults. Age Ageing. 2004;33(4):342-8.
37. Herman S, Kiely DK, Leveille S, et al. Upper and lower limb muscle power relationships in mobility-limited older adults. J Gerontol A Biol Sci Med Sci. 2005;60(4):476-80.
38. Portegijs E, Sipila S, Alen M, et al. Leg extension power asymmetry and mobility limitation in healthy older women. Arch Phys Med Rehabil. 2005;86(9):1838-42.
39. Sayers SP, Guralnik JM, Thombs LA, et al. Effect of leg muscle contraction velocity on functional performance in older men and women. J Am Geriatr Soc. 2005;53(3):467-71.
40. Holviala JH, Sallinen JM, Kraemer WJ, et al. Effects of strength training on muscle strength characteristics, functional capabilities, and balance in middle-aged and older women. J Strength Cond Res. 2006;20(2):336-44.
41. Kuo HK, Leveille SG, Yen CJ, et al. Exploring how peak leg power and usual gait speed are linked to late-life disability: data from the National Health and Nutrition Examination Survey (NHANES), 1999-2002. Am J Phys Med Rehabil. 2006;85(8):650-8.
42. Marsh AP, Miller ME, Saikin AM, et al. Lower extremity strength and power are associated with 400-meter walk time in older adults: The InCHIANTI study. J Gerontol A Biol Sci Med Sci. 2006;61(11):1186-93.
43. Bean JF, Kiely DK, LaRose S, et al. Is stair climb power a clinically relevant measure of leg power impairments in at-risk older adults? Arch Phys Med Rehabil. 2007;88(5):604-9.
44. Bonnefoy M, Jauffret M, Jusot JF. Muscle power of lower extremities in relation to functional ability and nutritional status in very elderly people. J Nutr Health Aging. 2007;11(3):223-8.
45. Perry MC, Carville SF, Smith IC, et al. Strength, power output and symmetry of leg muscles: effect of age and history of falling. Eur J Appl Physiol. 2007;100(5):553-61.
46. Puthoff ML, Nielsen DH. Relationships among impairments in lower-extremity strength and power, functional limitations, and disability in older adults. Phys Ther. 2007;87(10):1334-47.
47. Arai T, Obuchi S, Shiba Y, et al. The feasibility of measuring joint angular velocity with a gyro-sensor. Arch Phys Med Rehabil. 2008;89(1):95-9.
48. Bean JF, Kiely DK, LaRose S, et al. Which impairments are most associated with high mobility performance in older adults? Implications for a rehabilitation prescription. Arch Phys Med Rehabil. 2008;89(12):2278-84.
49. Clemencon M, Hautier CA, Rahmani A, et al. Potential role of optimal velocity as a qualitative factor of physical functional performance in women aged 72 to 96 years. Arch Phys Med Rehabil. 2008;89(8):1594-9.

50. Mayson DJ, Kiely DK, LaRose SI, et al. Leg strength or velocity of movement: which is more influential on the balance of mobility limited elders? Am J Phys Med Rehabil. 2008;87(12):969-76.
51. Portegijs E, Sipila S, Rantanen T, et al. Leg extension power deficit and mobility limitation in women recovering from hip fracture. Am J Phys Med Rehabil. 2008;87(5):363-70.
52. Carabello RJ, Reid KF, Clark DJ, et al. Lower extremity strength and power asymmetry assessment in healthy and mobility-limited populations: reliability and association with physical functioning. Aging Clin Exp Res. 2010;22(4):324-9.
53. Garcia PA, Dias JM, Dias RC, et al. A study on the relationship between muscle function, functional mobility and level of physical activity in community-dwelling elderly. Rev Bras Fisioter. 2011;15(1):15-22.
54. Van Roie E, Verschueren SM, Boonen S, et al. Force-velocity characteristics of the knee extensors: an indication of the risk for physical frailty in elderly women. Arch Phys Med Rehabil. 2011;92(11):1827-32.
55. Arai T, Obuchi S, Shiba Y, et al. The validity of an assessment of maximum angular velocity of knee extension (KE) using a gyroscope. Arch Gerontol Geriatr. 2012;54(2):e175-80.
56. Muehlbauer T, Besemer C, Wehrle A, et al. Relationship between strength, power and balance performance in seniors. Gerontology. 2012;58(6):504-12.
57. Pojednic RM, Clark DJ, Patten C, et al. The specific contributions of force and velocity to muscle power in older adults. Exp Gerontol. 2012;47(8):608-13.
58. Casas-Herrero A, Cadore EL, Zambom-Ferraresi F, et al. Functional capacity, muscle fat infiltration, power output, and cognitive impairment in institutionalized frail oldest old. Rejuvenation Res. 2013;16(5):396-403.
59. Paul SS, Sherrington C, Fung VS, et al. Motor and cognitive impairments in Parkinson disease: relationships with specific balance and mobility tasks. Neurorehabil Neural Repair. 2013;27(1):63-71.
60. Forte R, Boreham CA, De Vito G, et al. Measures of static postural control moderate the association of strength and power with functional dynamic balance. Aging Clin Exp Res. 2014;26(6):645-53.
61. Jenkins ND, Buckner SL, Bergstrom HC, et al. Reliability and relationships among handgrip strength, leg extensor strength and power, and balance in older men. Exp Gerontol. 2014;58:47-50.
62. Stenroth L, Sillanpaa E, McPhee JS, et al. Plantarflexor Muscle-Tendon Properties are Associated With Mobility in Healthy Older Adults. J Gerontol A Biol Sci Med Sci. 2015;70(8):996-1002.
63. Harries UJ, Bassey EJ. Torque-velocity relationships for the knee extensors in women in their 3rd and 7th decades. Eur J Appl Physiol Occup Physiol. 1990;60(3):187-90.
64. Metter EJ, Conwit R, Tobin J, et al. Age-associated loss of power and strength in the upper extremities in women and men. J Gerontol A Biol Sci Med Sci. 1997;52(5):B267-76.
65. De Vito G, Bernardi M, Forte R, et al. Determinants of maximal instantaneous muscle power in women aged 50-75 years. Eur J Appl Physiol Occup Physiol. 1998;78(1):59-64.
66. Kostka T. Quadriceps maximal power and optimal shortening velocity in 335 men aged 23-88 years. Eur J Appl Physiol. 2005;95(2-3):140-5.
67. Petrella JK, Kim JS, Tuggle SC, et al. Age differences in knee extension power, contractile velocity, and fatigability. J Appl Physiol (1985). 2005;98(1):211-20.
68. Clark DJ, Pojednic RM, Reid KF, et al. Longitudinal decline of neuromuscular activation and power in healthy older adults. J Gerontol A Biol Sci Med Sci. 2013;68(11):1419-25.
69. Miller MS, Bedrin NG, Callahan DM, et al. Age-related slowing of myosin actin cross-bridge kinetics is sex specific and predicts decrements in whole skeletal muscle performance in humans. J Appl Physiol (1985). 2013;115(7):1004-14.
70. Reid KF, Pasha E, Doros G, et al. Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. Eur J Appl Physiol. 2014;114(1):29-39.
71. Candow DG, Chilibeck PD. Differences in size, strength, and power of upper and lower body muscle groups in young and older men. J Gerontol A Biol Sci Med Sci. 2005;60(2):148-56.
72. Evans WJ. Exercise strategies should be designed to increase muscle power. J Gerontol A Biol Sci Med Sci. 2000;55(6):M309-10.
73. Buchner DM, Larson EB, Wagner EH, et al. Evidence for a non-linear relationship between leg strength and gait speed. Age Ageing. 1996;25(5):386-91.
74. Ferrucci L, Guralnik JM, Buchner D, et al. Departures from linearity in the relationship between measures of muscular strength and physical performance of the lower extremities: the Women's Health and Aging Study. J Gerontol A Biol Sci Med Sci. 1997;52(5):M275-85.
75. Salem GJ, Wang MY, Young JT, et al. Knee strength and lower- and higher-intensity functional performance in older adults. Med Sci Sports Exerc. 2000;32(10):1679-84.
76. Pearson SJ, Cobbold M, Orrell RW, et al. Power output and muscle myosin heavy chain composition in young and elderly men. Med Sci Sports Exerc. 2006;38(9):1601-7.

77. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing. 2002;31(2):119-25.
78. Portegijs E, Sipila S, Pajala S, et al. Asymmetrical lower extremity power deficit as a risk factor for injurious falls in healthy older women. J Am Geriatr Soc. 2006;54(3):551-3.
79. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. Arch Phys Med Rehabil. 2001;82(7):872-8.
80. Hruda KV, Hicks AL, McCartney N. Training for muscle power in older adults: effects on functional abilities. Can J Appl Physiol. 2003;28(2):178-89.
81. Macaluso A, Young A, Gibb KS, et al. Cycling as a novel approach to resistance training increases muscle strength, power, and selected functional abilities in healthy older women. J Appl Physiol (1985). 2003;95(6):2544-53.
82. Miszko TA, Cress ME, Slade JM, et al. Effect of strength and power training on physical function in community-dwelling older adults. J Gerontol A Biol Sci Med Sci. 2003;58(2):171-5.
83. Sayers SP, Bean J, Cuoco A, et al. Changes in function and disability after resistance training: does velocity matter?: a pilot study. Am J Phys Med Rehabil. 2003;82(8):605-13.
84. Bean JF, Herman S, Kiely DK, et al. Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. J Am Geriatr Soc. 2004;52(5):799-804.
85. Ramsbottom R, Ambler A, Potter J, et al. The effect of 6 months training on leg power, balance, and functional mobility of independently living adults over 70 years old. J Aging Phys Act. 2004;12(4):497-510.
86. de Vreede PL, Samson MM, van Meeteren NL, et al. Functional-task exercise versus resistance strength exercise to improve daily function in older women: a randomized, controlled trial. J Am Geriatr Soc. 2005;53(1):2-10.
87. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. Gerontology. 2005;51(2):108-15.
88. Orr R, de Vos NJ, Singh NA, et al. Power training improves balance in healthy older adults. J Gerontol A Biol Sci Med Sci. 2006;61(1):78-85.
89. Bottaro M, Machado SN, Nogueira W, et al. Effect of high versus low-velocity resistance training on muscular fitness and functional performance in older men. Eur J Appl Physiol. 2007;99(3):257-64.
90. Henwood TR, Riek S, Taaffe DR. Strength versus muscle power-specific resistance training in community-dwelling older adults. J Gerontol A Biol Sci Med Sci. 2008;63(1):83-91.
91. Onambele GL, Maganaris CN, Mian OS, et al. Neuromuscular and balance responses to flywheel inertial versus weight training in older persons. J Biomech. 2008;41(15):3133-8.
92. Portegijs E, Kallinen M, Rantanen T, et al. Effects of resistance training on lower-extremity impairments in older people with hip fracture. Arch Phys Med Rehabil. 2008;89(9):1667-74.
93. Bean JF, Kiely DK, LaRose S, et al. Increased velocity exercise specific to task training versus the National Institute on Aging's strength training program: changes in limb power and mobility. J Gerontol A Biol Sci Med Sci. 2009;64(9):983-91.
94. Marsh AP, Miller ME, Rejeski WJ, et al. Lower extremity muscle function after strength or power training in older adults. J Aging Phys Act. 2009;17(4):416-43.
95. Chen PY, Wei SH, Hsieh WL, et al. Lower limb power rehabilitation (LLPR) using interactive video game for improvement of balance function in older people. Arch Gerontol Geriatr. 2012;55(3):677-82.
96. Drey M, Zech A, Freiberger E, et al. Effects of strength training versus power training on physical performance in prefrail community-dwelling older adults. Gerontology. 2012;58(3):197-204.
97. Pereira A, Izquierdo M, Silva AJ, et al. Effects of high-speed power training on functional capacity and muscle performance in older women. Exp Gerontol. 2012;47(3):250-5.
98. Sayers SP, Gibson K, Cook CR. Effect of high-speed power training on muscle performance, function, and pain in older adults with knee osteoarthritis: a pilot investigation. Arthritis Care Res (Hoboken). 2012;64(1):46-53.
99. Lohne-Seiler H, Torstveit MK, Anderssen SA. Traditional versus functional strength training: effects on muscle strength and power in the elderly. J Aging Phys Act. 2013;21(1):51-70.
100. Balachandran A, Krawczyk SN, Potiaumpai M, et al. High-speed circuit training vs hypertrophy training to improve physical function in sarcopenic obese adults: A randomized controlled trial. Exp Gerontol. 2014;60:64-71.
101. Beltran Valls MR, Dimauro I, Brunelli A, et al. Explosive type of moderate-resistance training induces functional, cardiovascular, and molecular adaptations in the elderly. Age (Dordr). 2014;36(2):759-72.
102. Cadore EL, Casas-Herrero A, Zambom-Ferraresi F, et al. Multicomponent exercises including muscle power training enhance muscle mass, power output, and functional outcomes in institutionalized frail nonagenarians. Age (Dordr). 2014;36(2):773-85.

103. Gianoudis J, Bailey CA, Ebeling PR, et al. Effects of a targeted multimodal exercise program incorporating high-speed power training on falls and fracture risk factors in older adults: a community-based randomized controlled trial. J Bone Miner Res. 2014;29(1):182-91.
104. Pamukoff DN, Haakonssen EC, Zaccaria JA, et al. The effects of strength and power training on single-step balance recovery in older adults: a preliminary study. Clin Interv Aging. 2014;9:697-704.
105. Ramirez-Campillo R, Castillo A, de la Fuente CI, et al. High-speed resistance training is more effective than low-speed resistance training to increase functional capacity and muscle performance in older women. Exp Gerontol. 2014;58:51-7.
106. Reid KF, Martin KI, Doros G, et al. Comparative effects of light or heavy resistance power training for improving lower extremity power and physical performance in mobility-limited older adults. J Gerontol A Biol Sci Med Sci. 2014.
107. Wilhelm EN, Rech A, Minozzo F, et al. Concurrent strength and endurance training exercise sequence does not affect neuromuscular adaptations in older men. Exp Gerontol. 2014;60:207-14.
108. Correa CS, LaRoche DP, Cadore EL, et al. 3 Different types of strength training in older women. Int J Sports Med. 2012;33(12):962-9.
109. Paul SS, Canning CG, Song J, et al. Leg muscle power is enhanced by training in people with Parkinson's disease: a randomized controlled trial. Clin Rehabil. 2014;28(3):275-88.
110. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. Med Sci Sports Exerc. 2010;42(5):902-14.
111. Tschopp M, Sattelmayer MK, Hilfiker R. Is power training or conventional resistance training better for function in elderly persons? A meta-analysis. Age Ageing. 2011;40(5):549-56.
112. Signorile JF, Carmel MP, Lai S, et al. Early plateaus of power and torque gains during high- and low-speed resistance training of older women. J Appl Physiol (1985). 2005;98(4):1213-20.
113. van Tulder M, Furlan A, Bombardier C, et al. Updated method guidelines for systematic reviews in the cochrane collaboration back review group. Spine (Phila Pa 1976). 2003;28(12):1290-9.
114. Signorile JF, Carmel MP, Czaja SJ, et al. Differential increases in average isokinetic power by specific muscle groups of older women due to variations in training and testing. J Gerontol A Biol Sci Med Sci. 2002;57(10):M683-90.
115. Fielding RA, LeBrasseur NK, Cuoco A, et al. High-velocity resistance training increases skeletal muscle peak power in older women. J Am Geriatr Soc. 2002;50(4):655-62.
116. Delmonico MJ, Kostek MC, Doldo NA, et al. Effects of moderate-velocity strength training on peak muscle power and movement velocity: do women respond differently than men? J Appl Physiol (1985). 2005;99(5):1712-8.
117. Petrella JK, Kim JS, Tuggle SC, et al. Contributions of force and velocity to improved power with progressive resistance training in young and older adults. Eur J Appl Physiol. 2007;99(4):343-51.
118. Sayers SP, Gibson K. A comparison of high-speed power training and traditional slow-speed resistance training in older men and women. J Strength Cond Res. 2010;24(12):3369-80.
119. Henwood TR, Taaffe DR. Short-term resistance training and the older adult: the effect of varied programmes for the enhancement of muscle strength and functional performance. Clin Physiol Funct Imaging. 2006;26(5):305-13.
120. Bean JF, Kiely DK, LaRose S, et al. Are changes in leg power responsible for clinically meaningful improvements in mobility in older adults? J Am Geriatr Soc. 2010;58(12):2363-8.
121. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. Sports Med. 2011;41(2):125-46.
122. Skelton DA, Young A, Greig CA, et al. Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. J Am Geriatr Soc. 1995;43(10):1081-7.
123. Bean J, Herman S, Kiely DK, et al. Weighted stair climbing in mobility-limited older people: a pilot study. J Am Geriatr Soc. 2002;50(4):663-70.
124. Capodaglio P, Capodaglio Edda M, Facioli M, et al. Long-term strength training for community-dwelling people over 75: impact on muscle function, functional ability and life style. Eur J Appl Physiol. 2007;100(5):535-42.
125. Galvao DA, Taaffe DR. Resistance exercise dosage in older adults: single- versus multiset effects on physical performance and body composition. J Am Geriatr Soc. 2005;53(12):2090-7.
126. Taaffe DR, Duret C, Wheeler S, et al. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. J Am Geriatr Soc. 1999;47(10):1208-14.
127. Izquierdo M, Ibanez J, K HA, et al. Once weekly combined resistance and cardiovascular training in healthy older men. Med Sci Sports Exerc. 2004;36(3):435-43.
128. Stiggelbout M, Popkema DY, Hopman-Rock M, et al. Once a week is not enough: effects of a widely implemented group based exercise programme for older adults; a randomised controlled trial. J Epidemiol Community Health. 2004;58(2):83-8.

129. DiFrancisco-Donoghue J, Werner W, Douris PC. Comparison of once-weekly and twice-weekly strength training in older adults. Br J Sports Med. 2007;41(1):19-22.
130. Nakamura Y, Tanaka K, Yabushita N, et al. Effects of exercise frequency on functional fitness in older adult women. Arch Gerontol Geriatr. 2007;44(2):163-73.
131. Foley A, Hillier S, Barnard R. Effectiveness of once-weekly gym-based exercise programmes for older adults post discharge from day rehabilitation: a randomised controlled trial. Br J Sports Med. 2011;45(12):978-86.
132. Sousa N, Mendes R, Abrantes C, et al. Is once-weekly resistance training enough to prevent sarcopenia? J Am Geriatr Soc. 2013;61(8):1423-4.
133. Farinatti PT, Geraldes AA, Bottaro MF, et al. Effects of different resistance training frequencies on the muscle strength and functional performance of active women older than 60 years. J Strength Cond Res. 2013;27(8):2225-34.
134. Westcott WL, Winett RA, Annesi JJ, et al. Prescribing physical activity: applying the ACSM protocols for exercise type, intensity, and duration across 3 training frequencies. Phys Sportsmed. 2009;37(2):51-8.
135. McCartney N, Hicks AL, Martin J, et al. Long-term resistance training in the elderly: effects on dynamic strength, exercise capacity, muscle, and bone. J Gerontol A Biol Sci Med Sci. 1995;50(2):B97-104.
136. McCartney N, Hicks AL, Martin J, et al. A longitudinal trial of weight training in the elderly: continued improvements in year 2. J Gerontol A Biol Sci Med Sci. 1996;51(6):B425-33.
137. Sylliaas H, Brovold T, Wyller TB, et al. Prolonged strength training in older patients after hip fracture: a randomised controlled trial. Age Ageing. 2012;41(2):206-12.
138. Lexell J, Downham DY, Larsson Y, et al. Heavy-resistance training in older Scandinavian men and women: short- and long-term effects on arm and leg muscles. Scand J Med Sci Sports. 1995;5(6):329-41.
139. Hakkinen K, Alen M, Kallinen M, et al. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. Eur J Appl Physiol. 2000;83(1):51-62.
140. Henwood TR, Taaffe DR. Detraining and retraining in older adults following long-term muscle power or muscle strength specific training. J Gerontol A Biol Sci Med Sci. 2008;63(7):751-8.
141. Pereira A, Izquierdo M, Silva AJ, et al. Muscle performance and functional capacity retention in older women after high-speed power training cessation. Exp Gerontol. 2012;47(8):620-4.
142. Mitchell SL, Stott DJ, Martin BJ, et al. Randomized controlled trial of quadriceps training after proximal femoral fracture. Clin Rehabil. 2001;15(3):282-90.
143. Zech A, Drey M, Freiberger E, et al. Residual effects of muscle strength and muscle power training and detraining on physical function in community-dwelling prefrail older adults: a randomized controlled trial. BMC Geriatr. 2012;12:68.
144. Kennis E, Verschueren SM, Bogaerts A, et al. Long-term impact of strength training on muscle strength characteristics in older adults. Arch Phys Med Rehabil. 2013;94(11):2054-60.

Figures

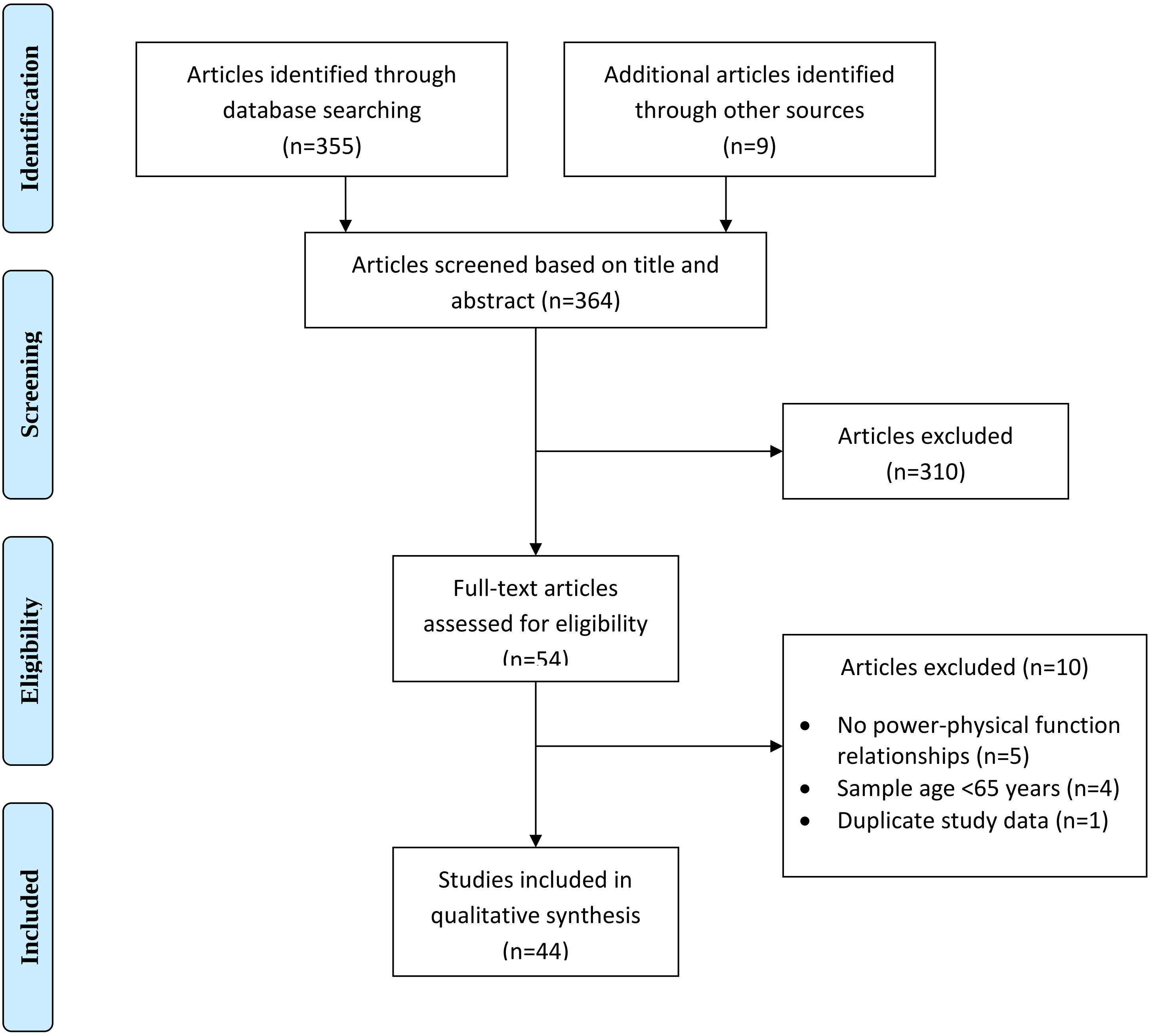

Figure 1: PRISMA flow diagram for the systematic review of the relationship between muscle power and physical function in older people.

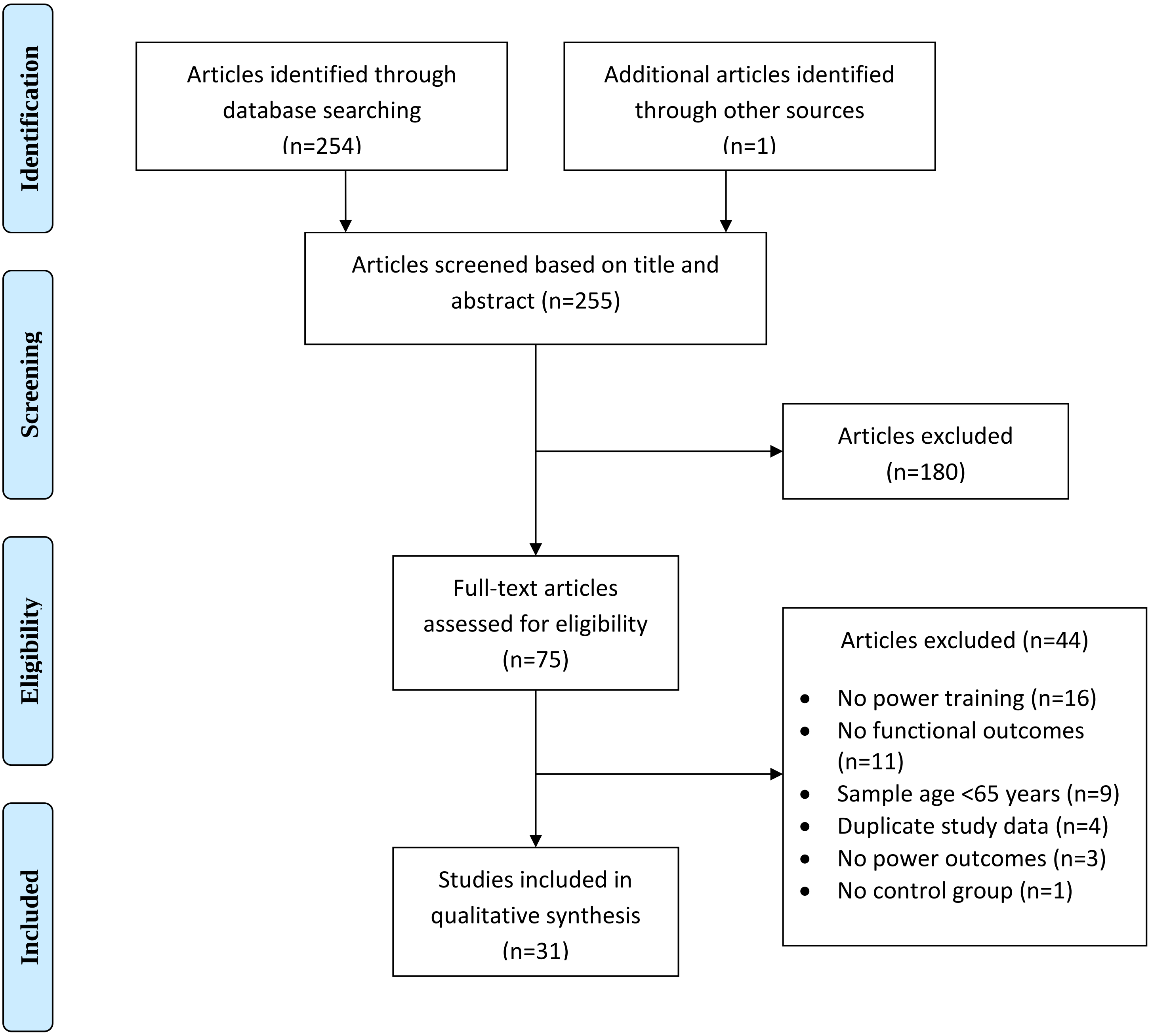

Figure 2: PRISMA flow diagram for the systematic review of power training interventions to improve muscle power and physical function in older people.

Table 1: Summary of studies examining the relationships between muscle power and muscle strength with physical functional performance.

Study	Sample	Independent variable	Dependent variable	Analysis	Variance explained (R^2, %)
Skelton et al. (1994)[21]	100 M&W: 65-89 y Community dwelling	Leg extensor power Isometric knee extensor strength	CR, MBS	Spearman rank correlation	CR: Power 0.38-0.56, Strength 0.35-0.50 MBS: Power 0.47-0.58, Strength NS.
Earles et al. (1997)[23]	230 M&W: 77 ± 5 y Community dwelling	Leg press power Leg press 1RM strength	SPPB	Pearson correlation	Power 13%, Strength NS.
Foldvari et al. (2000)[25]	80 W: 74.8 ± 5.0 y Community dwelling	Leg press, chest press, upper back, & hip abduction power & strength	Functional status questionnaire	Bivariate regression	Power 22%, Strength 18%
Samson et al. (2000)[27]	155 M&W, 20-90 y Healthy population	Leg extensor power Isometric knee extensor strength	TUG 2MWT	Pearson's correlation	TUG: Power 35-55%, Strength 36-50% 2MWT: Power 25-56%, Strength 21-49%
Suzuki et al. (2001)[28]	34 W: 75.4 ± 5.1 y Living independently	Isokinetic ankle plantar flexor & dorsi flexor power & strength	CR, SC, MWS, NWS	Bivariate regression	CR: Power DF 25%, Strength DF NS SC: Power DF 24%, Strength PF 16% NWS: Power DF 22%, Strength PF 28% MWS: Power PF 22%, Strength PF 18%
Bean et al. (2002)[29]	45 M&W: 72.7 ± 4.6 y Community dwelling	Sum leg press & knee extension power & strength	SPPB, CR, SC, TG, MWS, NWS	Bivariate regression	SPPB: Power 15%, Strength 12% CR: Power 14%, Strength 10% SC: Power 27%, Strength 19% TG: Power 12%, Strength 6% NWS: Power 26%, Strength 21% MWS: Power 45%, Strength 46%
Bean et al. (2002)[30]	45 M&W: 72.7 ± 4.6 Community dwelling	Leg press, knee extensor, ankle plantar flexor power & strength	6 MWT	Bivariate regression	Power 21-37%, Strength 20-27%
Bean et al. (2003)[32]	839 M&W: 74.2 ± 6.6 y Community dwelling	Leg extensor power, isometric hip & knee extensor strength	SPPB, CR, SB, SC, NWS	Bivariate regression	SPPB: Power 28%, Strength 27% CR: Power 22%, Strength 23% SB: Power 27%, Strength 25% SC: Power 38%, Strength 36% NWS: Power 38%, Strength 36%
Cuoco et al. (2004)[35]	47 M&W: 72.7 ± 8 y Community dwelling	Leg press power & strength	CR, SC, NWS	Bivariate regression	CR: Power 12-15%, Strength 9% SC: Power 14-18%, Strength 10% NWS: Power 26-35%, Strength NS
Marsh et al. (2006)[42]	720 M&W, 73.0 ± 6.1 y General population	Leg extensor power, isometric ankle plantar flexor strength	400mWT	Multivariate regression	Power 31%, Strength 25%

Study	Sample	Independent variable	Dependent variable	Analysis	Variance explained (R^2, %)
Puthoff & Nielsen (2007)[46]	30 M&W: 77.3 ± 7.0 y Community dwelling	Leg press power & strength	SPPB, CR, NWS, 6 MWT, LLFDI	Bivariate regression	SPPB: Power 26-39%, Strength 28% CR: Power 20-34%, Strength 29% NWS: Power 24-35%, Strength 31% 6 MWT: Power 43-48%, Strength 38% LLFDI: Power 31-35%, Strength 32%
Larsen et al. (2009)[16]	17 W: 72.4 ± 6.4 y Community dwelling healthy	Countermovement jump power Knee extensor & flexor strength	SC	Bivariate regression	Power 48-56%, Strength 26-45%
Carabello et al. (2010)[52]	28 M&W healthy: 74.0 ± 3.6 y 34 M&W mobility limited: 77.8 ± 4.5 y	Knee extensor power & strength	SPPB, SC, CR, NWS	Spearman rank correlation	SPPB, SC, NWS: Power NS, Strength NS CR: Power -0.50, Strength -0.50
Forte et al. (2014)[60]	57 M&W healthy: 24 M 70.0 ± 3.3 y; 33 W 69.0 ± 3.3 y	Countermovement jump power Knee extensor strength	NWS, MWS	Pearson correlation	NWS: Power 7%, Strength 7% MWS: Power 8%, Strength 9%
Jenkins et al. (2014)[61]	16 M: 72.1 ± 7.1 y	Knee extensor power & strength	FR	Pearson correlation	Power 21-28%, Strength 29-38%
Stenroth et al. (2015)[62]	52 M&W: 74.8 ± 3.3 y	Countermovement jump power Knee extensor & ankle PF strength	TUG, 6MWT	Partial correlation	TUG: Power 18%, KE Strength 8%, PF Strength 19%. 6MWT: Power 20%, KE Strength 13%, PF Strength 23%.

Abbreviations: CR, chair rise time for *n* repetitions or time for *n* repetitions; DF, ankle dorsiflexion; FR, functional reach; KE, knee extensor; LLFDI, Late Life Function and Disability Instrument self-report questionnaire; M, men; MBS, maximum box step height; MWS, maximum walking speed for a given distance; NS = association is statistically non-significant; NWS, normal walking speed for a given distance; PF, ankle plantar flexion; SB, standing balance test; SC, stair climb time; SPPB, short physical performance battery (based on 0-4 score on 3 functional tasks (habitual gait speed, standing balance, 5 repetition chair rise time) providing composite score of 0-12); TG, tandem gait time for a given distance; TUG, timed up and go; W, women; y, age in years as mean ± SD or range; 1RM, one repetition maximum measure of strength; 2MWT, two-minute walk test distance; 6MWT, six-minute walk test distance; 400mWT, 400 metre walk test time.

Table 2: Summary of studies examining force and velocity relationships with functional performance.

Study	Sample	Independent variables	Dependent variables	Statistical model	Variance explained (R^2, %)
Sayers et al. (2005)[39]	101 M&W: 75-90 y Community dwelling	Leg press 1RM Leg press velocity at 40% 1RM (V)	SPPB 400mWT	Forward selection multivariate regression	SPPB: 0-22% 1RM, 8-9% V; 400mWT: 0-12% 1RM, 16-24% V
Arai et al. (2008)[47]	113 M&W: 75.1 ± 5.2 y Community dwelling	Standing plantar flexion maximal velocity (V)	FR, TUG, MWS, NWS, SLS	Pearson correlation	FR: 13% V, TUG: 16% V MWS: 19% V, NWS: 16% V, SLS: 9% V
Bean et al. (2008)[48]	138 M&W: 75.4 ± 6.9 y Community dwelling	Leg press 1RM tertile Leg press velocity at 40% 1RM tertile (V)	SPPB status (>9) ETT tertile BBT	Pearson correlation	SPPB: 5% 1RM, 5% V ETT: 6% 1RM, 7% V BBT: 0% 1RM (NS), 10% V
Clémençon et al. (2008)[49]	39 W: 83.3 ± 5.8 y Retirement home residents	Optimal velocity (V) Optimal torque (T)	CR, SC, MWS	Forward stepwise multivariate regression	CR: 47% V SC: 90% V MWS: 49% V
Mayson et al. (2008)[50]	138 M&W: 75.4 ± 6.9 y Community dwelling	Leg press 1RM Leg press velocity at 40% 1RM (V)	BBT (0-56) DGI (0-24) POMA (0-28) UST	Multivariate logistic regression with odds ratio to categorize % likelihood good balance	BBT ≥50: 0.08 1RM, 14.2 V DGI >20: 35.8 V POMA >25: 33.92 V UST ≥ 5s: 1.06 1RM
Larsen et al. (2009)[16]	17 W: 72.4 ± 6.4 y Community dwelling healthy	Countermovement jump force Countermovemnt jump velocity (V)	SC	Bivariate regression	3% Force (NS), 78% V
Van Roie et al. (2011)[54]	123 W: 79.7 ± 5.3 y Supported living	Knee extension isometric MVC Knee extension maximal unloaded velocity (V)	mPPT	Pearson correlation	mPPT: 32% MVC, 46% V
Arai et al. (2012)[55]	105 M&W: 75.0 ± 5.3 y Community dwelling	Knee extension isometric MVC Knee extension maximal velocity with 2 kg load (V)	FR, TUG, MWS, NWS	Pearson correlation	FR: 14% MVC, 13% V TUG: 5% MVC, 18% V MWS: 19% MVC, 35% V NWS: 6% MVC, 6% V
Pojednic et al. (2012)[57]	25 M&W: 77.9 ± 4.3 y Mobility limited, community dwelling	Knee extension isometric MVC Leg press velocity at 40% 1RM (V)	SLS CR, SC	Multivariate regression	CR: 59%; MVC (NS), V (*P*=0.0007) SC: 29%; MVC (NS), V (*P*=0.034)

Abbreviations: BBT, Berg balance test; CR, chair rise time for *n* repetitions or time for *n* repetitions; DGI, dynamic gait index; ETT, exercise tolerance test; FR, functional reach; M, men; mPPT, modified physical performance test; MVC, maximal voluntary isometric contraction; MWS, maximal walking speed for a given distance; NS = association is statistically non-significant; NWS, normal walking speed for a given distance; *P*, statistical probability; POMA, performance-orientated mobility assessment; SC, stair climb time; SLS, single leg stand; SPPB, short physical performance battery (based on 0-4 score on 3 functional tasks (habitual gait speed, standing balance, 5 repetition chair rise time) providing composite score of 0-12); T, peak torque measure of strength; TUG, timed up and go; UST, unipedal stance test; V, maximal angular velocity of movement; W, women; y, age in years as mean ± SD or range; 1RM, one repetition maximum measure of strength; 400mWT, 400 metre walk test time.

Table 3: Summary of studies comparing the effectiveness of high velocity power training (PT) versus low velocity traditional resistance training (TRT) on muscle power and physical functional performance in older people.

Study	Sample	Duration (weeks)	Frequency (days)	Training modality	Training content	Power outcomes	Functional outcomes	Risk of bias[a]
Miszko et al. (2003)[82]	39 M&W, PT 72.3 y, TRT 72.8 y, CON 72.4 y	16	3	Pneumatic machines	9 UL/LL, 3 sets x 6-8 reps at 40% (PT), at 50-80% 1RM (TRT)	PT = TRT	PT > TRT	Unclear High
Sayers et al. (2003)[83]	30 W, 15 PT 73.2 y, 15 TRT 72.1 y	16	3	Pneumatic machines	2 LL, 3 sets x 8 reps at 70% 1RM	PT 97% > TRT 45%	PT = TRT	Unclear Unclear
Bottaro et al. (2007)[89]	20 M, 11 PT 66.6 y, 9 TRT 66.3 y	10	2	Machines	7 UL/LL, 3 sets x 8-10 reps at 60% 1RM	PT 31-37% > TRT 8-13%	PT 15-50% > TRT 1-6%	Unclear Unclear
Henwood et al. (2008)[90]	53 M&W, 19 PT 71.2 y, TRT 69.6 y, CON 69.3 y	24	2	Machines	6 UL/LL, 3 sets x 8 reps at 45-75% (PT), at 75% 1RM (TRT)	PT 51% = TRT 34%	PT = TRT	Unclear Unclear
Onambele et al. (2008)[91]	24 M&W 69.9 y, 12 PT, 12 TRT	12	3	Machines	2LL, 1-4 sets x 8-12 reps at maximal power (PT), at 80% 1RM (TRT)	PT 28% > TRT 4%	PT > TRT	Unclear Unclear
Bean et al. (2009)[93]	117 M&W, 72 PT 74.7 y, 66 TRT 76.1 y	16	3	Weighted vests	10 UL/LL, 2 sets x 10 reps, weighted vest task-specific exercises (PT), isolated free-weight exercises (TRT)	PT > TRT	PT = TRT	Low Low
Marsh et al. (2009)[94]	38 M&W 74.8 y, 12 PT, 11 TRT, 15 CON	12	3	Pneumatic machines	2 LL/5 UL, 3 sets x 8-10 reps at 70% 1RM	PT 34-41% > TRT 19-22%	PT = TRT	Low Unclear
Correa et al. (2012)[108]	58 W 67 ± 5 y, 13 PT, 14 PT+SSC, 14 TRT, 17 CON	6	2	Machines Box jump	3 LL, 3-4 sets x 8-10 reps (PT, TRT) 3 LL, 3-4 sets x 8-10 reps + 3-4 sets lateral box jump x 15-20 s (PT+SSC)	PT+SSC 25% > PT 8% + TRT 4%	PT+SSC 17% > PT 8% + TRT 7%	Unclear Unclear
Drey et al. (2012)[96]	69 M&W 70-84 y, 24 PT, 23 TRT, 22 CON	12	2	Resistance band machine, body weight	7 LL/1 UL, 2 sets x 15 reps at 10-11 RPE, progress to 2 sets x 6 reps at 16 RPE	PT = TRT	PT = TRT	Low Low
Sayers et al. (2012)[98]	33 M&W 67.6 y, 10 PT, 12 TRT, 11 CON	12	3	Pneumatic machines	2 LL. 3 sets x 12-14 reps at 40% 1RM (PT), 8-10 reps at 80% 1RM (TRT)	PT > TRT	PT = TRT	Low Low
Balachandran et al. (2014)[100]	17 M&W, 8 PT 71.6 y, 9 TRT 71 y	15	2	Pneumatic machines	11 UL/LL, 3 sets x 10-12 reps at 50-80% 1RM (PT), at 70% 1RM (TRT)	PT > TRT	PT > TRT	Low Low
Pamukoff et al. (2014)[104]	15 M&W, 8 PT 73.4 y, 7 TRT 68.1 y	6	3	Pneumatic machines, Nautilus machines	7 LL, 3 sets x 8-10 reps at 50% 1RM	PT = TRT	PT = TRT	Unclear High
Ramirez-Campillo et al. (2014)[105]	45 W, 15 PT 66.3 y, 15 TRT 68.7 y, 15 CON 66.7 y	12	3	Bodyweight, machines, medicine ball	6 UL/LL, 3 sets x 8 reps at 45-75% 1RM (PT), at 75% 1RM (TRT)	PT > TRT	PT 14-18% > TRT 9-10%	Unclear Unclear

[a]Risk of bias assessed on two domains and judged as either ‘low risk’, ‘high risk’, or ‘unclear’. Upper term refers to risk of bias for random sequence generation and lower term refers to risk of bias for blinding of outcome assessors.
Abbreviations: CON, control group; LL, lower limb exercises; M, men; PT, power training; PT+SSC, power training with 1 additional plyometric stretch-shortening cycle exercise; reps, repetitions; RPE, rating of perceived exertion; TRT, traditional resistance training; UL, upper limb exercises; W, women; y, sample mean age in years; % 1RM, percentage of one repetition maximum. =, outcomes between groups are statistically non-significant; >, statistically significant greater outcome.

Table 4: Summary of studies investigating different power training loads on muscle power and physical function in older people.

Study	Sample	Duration (weeks)	Frequency (days)	Training methods	Training content	Power outcomes	Functional outcomes	Risk of bias[a]
Macaluso et al. (2003)[81]	20 W 65-74 y, 10 PT low, 10 PT high	16	3	Resisted cycling	1 LL 40% 2RM (PT low) 80% 2RM (PT high)	PT low = PT high	PT low = PT high	High Unclear
Orr et al. (2006)[88]	100 M&W 68.5 y, 25 PT low, 25 PT medium, 24 PT high, 26 CON	8-12	2	Pneumatic machines	2LL / 2UL 20% 1RM (PT low) 50% 1RM (PT medium) 80% 1RM (PT high)	PT low = PT medium &PT high	PT low 11% > PT medium 2.1% & PT high 0.3%	Low Unclear
Reid et al. (2014)[106]	52 M&W, 25 PT low 78.3 y, 27 PT high 77.6 y	16	2	Pneumatic machines	2 LL 40% 1RM (PT low) 70% 1RM (PT high)	PT low 34% = PT high 42%	PT low = PT high	Unclear Unclear

[a]Risk of bias assessed on two domains and judged as either 'low risk', 'high risk', or 'unclear'. Upper term refers to risk of bias for random sequence generation and lower term refers to risk of bias for blinding of outcome assessors.

Abbreviations: CON, control group; LL, lower limb exercises; M, men; PT, power training; UL, upper limb exercises; W, women; y, sample age in years as mean or range; % 1RM, percentage of one repetition maximum. =, outcomes between groups are statistically non-significant; >, statistically significant greater outcome.

Table 5: Summary of studies investigating various power training interventions on muscle power and physical function in older people.

Study	Sample	Duration (weeks)	Frequency (days)	Training methods	Training content	Power outcomes	Functional outcomes	Risk of bias[a]
Earles et al. (2001)[79]	43 M&W 78 y, 18 PT, 22 CON	12	2	Bodyweight, weight belts, machines, walking (CON)	5 LL	PT 22% > CON -9%	PT = CON	Unclear Unclear
Hruda et al. (2003)[80]	25 M&W, 18 PT 84.9 y, 7 CON 80.6 y	10	3	Bodyweight, resistance bands	8 LL	PT 60% > CON -3.9%	PT 32-66% > CON 1-3%	Low Unclear
Bean et al. (2004)[84]	21 W , 11 PT 77.1 y, 10 CON 78.9 y	12	3	Bodyweight, weighted vests	6 UL/LL	PT 12-36% > CON 4-14%	PT > CON 1/3 tasks	Unclear Unclear
Ramsbottom et al. (2004)[85]	16 M&W, 10 PT 75.6 y, 6 CON 77 y	24	2	Bodyweight, resistance bands	Seated, standing, floor, mobility, balance	PT 38% > CON 0%	PT > CON 2/3 tasks	Low High
Henwood & Taaffe (2005)[87]	24 M&W 69.9 y, 14 PT, 10 CON	8	2	Machines	7 UL/LL	PT ↑7-17%	PT ↑ 3/5 tasks 7-26%	High Unclear
de Vreede et al. (2005)[86]	98 W, 33 FTT 74.7 y, 34 TRT 74.8 y, 31 CON 73 y	12	3	Bodyweight, free weights, weighted vests, resistance bands	Functional tasks (FTT), UL/LL/core (TRT)	FTT = TRT	FTT > TRT	Low Low
Portegijs et al. (2008)[92]	46 M&W 60-85 y, 24 PT, 22 CON	12	2	Bodyweight, machines	5 LL	PT = CON	PT = CON	Low Unclear
Chen et al. (2012)[95]	40 M&W, 20 PT 76.4 y, 20 CON 75.4 y	6	2	Interactive video game	High velocity STS (PT), Low velocity STS, strength, balance (CON)	PT 64% > CON 8%	PT > CON 4/5 tasks	High Unclear
Pereira et al. (2012)[97]	56 W, 28 PT 62.5 y, 28 CON 62.2 y	12	3	Bodyweight, machines, medicine ball	6 UL/LL/core	PT 14-40% > CON	PT > CON 2/2 tasks	High Unclear
Lohne-Seiler et al. (2013)[99]	63 M&W, 23 PT 69.4 y, 30 FTT 70.4 y, 10 CON 69.3 y	11	2	Machines (PT), Bodyweight, free-weights, bands, obstacle course (FTT)	PT 4 UL, 1LL FTT 2 LL, 3 UL, obstacle course	PT ↑1/2 FTT ↑0/2 CON ↑1/2	PT ↑1/2 FTT ↑2/2 CON ↑0/2	High Unclear
Beltran Valls et al. (2014)[101]	23 M&W 72 y, 13 PT, 10 CON	12	2	Machines	2 UL, 2 LL	PT ↑18-36%, CON ↔ -2 to -5 %	PT ↑ 4/4 tasks 8-12%, CON ↔ 0-4%	Unclear Unclear
Cadore et al. (2014)[102]	24 M&W, 11 PT 93.4 y, 13 CON 90.1 y	12	2	Machines	1 UL, 2 LL, balance, gait, Functional exercises	PT ↑97-117%	PT > C 5/9 tasks	Unclear Unclear
Gianoudis et al. (2014)[103]	162 M&W, 81 PT 67.7 y, 81 CON 67.2 y	52	3	Machines, free-weights, bodyweight	Varied LL PT, dynamic weight-bearing, balance	PT 4.8% > CON	PT > CON 2/3 tasks	Low Unclear
Paul et al. (2014)[109]	40 M&W, 20 PT 68.1 y, 20 CON 64.5 y	12	2	Pneumatic machines	4 LL (PT) 3 LL + trunk (CON)	PT > CON 15-45%	PT = CON	Unclear Unclear

Wilhelm et al. (2014)[107]	36 M, 11 E-PT 63.2 y, 12 PT-E 67.1 y, 13 CON 65.8 y	12	2	Machines, free-weights	4 UL, 3 LL, cycling	E-PT = PT-E > CON	E-PT = PT-E > CON 1/2 tasks	High Unclear

[a]Risk of bias assessed on two domains and judged as either 'low risk', 'high risk', or 'unclear'. Upper term refers to risk of bias for random sequence generation and lower term refers to risk of bias for blinding of outcome assessors.

Abbreviations: CON, control group; E-PT, endurance training prior to power training in each session; FTT, functional task training; LL, lower limb exercises; M, men; PT, power training; PT-E, power training prior to endurance training in each session; TRT, traditional resistance training; UL, upper limb exercises; W, women; y, sample age in years as mean or range; =, outcomes between groups are statistically non-significant; >, statistically significant greater outcome. ↑, statistically significant increase in outcome measure; ↔, no statistically significant change in outcome measure.