Dose–Response Relationship of Resistance Training in Older Adults: A Meta-Analysis

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BASIC SCIENCES

ABSTRACT

STEIB, S., D. SCHOENE, and K. PFEIFER. Dose–Response Relationship of Resistance Training in Older Adults: A Meta-Analysis. *Med. Sci. Sports Exerc.*, Vol. 42, No. 5, pp. 902–914, 2010. **Purpose**: The purpose of this study was to determine the dose–response relationship of resistance training (RT) to improve strength and function in older adults. **Methods**: A systematic literature search was performed in relevant databases and study reference lists to identify randomized controlled trials. Randomized controlled trials comparing the effects of different doses of strength training in older people (65 yr and older) on strength and functional outcomes were eligible. Two independent reviewers decided on study inclusion, extracted data, and assessed methodological quality. Standardized mean difference (SMD) and 95% confidence intervals (CI) were calculated for relevant outcomes and pooled using a random-effects model. **Results**: Twenty-nine trials with a total of 1313 subjects (mean age = 65–81 yr) are summarized in this review. Trials comparing different training intensities show strong effects of progressive resistance training (PRT) on maximal strength in a dose-dependent manner, with high-intensity (HI) PRT being more effective compared with moderate (MI)- and low-intensity (LI) PRT (SMD [HI vs LI] = 0.88, 95% CI = 0.21–1.55; SMD [HI vs MI] = 0.62, 95% CI = 0.22–1.03). PRT was also successful for improving functional outcomes, but gains were independent of training intensity. Power training (PT) was more effective for improving muscle power (SMD [PT vs PRT] = 1.66, 95% CI = 0.08–3.24) and functional outcomes than PRT. There was only little information available on training volume and frequency. **Discussion**: Higher training intensities are superior to lower intensities for improving maximal strength but not necessarily for functional performance of older adults. PT has shown to be a particularly effective method for enhancing muscle power and functional performance. More research is necessary to identify the effect of different training volumes and frequencies and the dose–response relationship for very old and frail populations. **Key Words:** STRENGTH, FUNCTION, PERFORMANCE, ELDERLY, FRAILTY

Loss of muscle strength and mass (i.e., sarcopenia) as well as impaired physical performance and mobility are among the most important age-related degeneration processes in humans (1,54). Strength decreases of 20%–40% for old and even higher for very old adults have been reported in the literature (3,54). These deficits are known to be caused by numerous qualitative and quantitative changes in the neuromuscular system. The quantitative loss is expressed in a decrease of muscle mass by up to 50% (1), resulting from a reduction in size and number of muscle fibers (3). Among the complex qualitative changes are alterations in fiber composition (decrease of type II fibers), neural activation, and increased antagonistic coactivation of the aged muscles (54). Another aspect of age-related degeneration is the substantial decrease of physical performance in older adults. Among the most important changes are problems with everyday tasks (activities of daily living [ADL]) and alterations of the motor control system leading to an impairment of mobility and eventually increasing the risk of falling and disability (33,41).

There is a consensus that the described neuromuscular changes are directly related to loss of mobility and function, affecting the independence and quality of life of the elderly (33). These deficits appear to be most dominant in tasks where a certain amount of strength is necessary to succeed (e.g., stair climbing) (45). Because functional performance and mobility are important factors for preserving the health status, independence, and well being of older adults, current intervention strategies aim at maintaining or improving strength and function in this target group.

Resistance training (RT) is a very frequently used strategy and has received increasing attention in recent research. Progressive resistance training (PRT) is the most commonly used type of strength training. There is a great deal of evidence indicating that PRT is an effective way for increasing muscle strength in older adults (32). It is also reported to be a safe method even for very old adults (17,43). However, in terms of improving physical performance, the evidence is limited. The beneficial effect of RT on some aspects of function, such as stair climbing, chair rise, or gait speed, is well documented, whereas for others such as balance (as a requirement

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for walking performance) and some ADL, effectiveness is still unclear (3,17,32). Recent studies report that muscle power (defined as force multiplied by velocity) seems to have a larger impact on functional abilities than muscle strength and that power training (PT), a strength-training method where the concentric phase is performed with maximal speed, could therefore be even more effective than PRT (23,39).

The above reported body of evidence indicates that RT is a successful training strategy to improve strength and physical performance of older adults. However, most of the studies do not reflect on recommendations for the type and especially the dose of RT programs, which are necessary for the prescription and design of interventions. Strength-training recommendations for older adults exist (1,2,38). However, there is still a lack of knowledge about the most adequate doses and types of RT. It is doubtful that an "optimal dose" of RT, in terms of one specific configuration of training variables that provide maximal benefits for all individuals, exists. Therefore, the "most adequate dose" will be used in the following to describe the set of training variables that produce the highest benefits in the respective study populations. The objective of this systematic review was to identify the effect of different intensities, durations, volumes, frequencies, and types of RT to enhance strength and physical performance in old and very old adults.

METHODS

Literature search strategy. A computerized literature search was performed (August 2008), and the results were scanned by two independent reviewers (S.S., D.S.). The searched databases were MEDLINE (PubMed), The Cochrane Library, and PEDro. The following keyword phrases and their combinations were used: dose, dose–response, intensity, volume, frequency, duration, density, break, low, moderate, high, strength, resistance, power, eccentric, negative work, isokinetic, isometric, training, exercise, intervention, function, performance, disability, balance, flexibility, ROM, gait, quality of life, ADL, elderly, old, older adults, and frail. Reference lists of the obtained articles were scanned for the identification of additional studies.

Selection criteria. Two reviewers independently scanned the obtained abstracts, and inclusion was decided by consensus. Only randomized controlled trials (RCT) were considered in this review. For studies comparing different types of RT, groups using the standard treatment (PRT, concentric isokinetic RT) were accepted as control groups.

To be eligible for inclusion, studies had to meet the following criteria: mean age of subjects 65 yr or older, strength training as the main intervention (defined as an exercise where the subject exerts an effort against an external resistance or his or her own body weight), and relevant outcome measures including muscle strength (typically assessed as one-repetition maximum [1RM] or maximal voluntary contraction [MVC]), muscle endurance, and peak muscle power as well as functional parameters related to mobility. Articles were only considered if a dose–response relationship was being investigated by comparing at least two different training doses or types.

Studies were excluded if designed for the treatment of a certain disease or if they included unsupervised training approaches (e.g., home-based training programs). There were no restrictions regarding the setting, the activity level, or the physical status of the subjects.

Assessment of methodological quality. The methodological quality of all eligible studies was independently examined by two reviewers, and disagreements were solved by discussion. The van Tulder scale for the assessment of internal study validity (53) was used. The scale includes the following items: a) acceptable method of randomization, b) concealed treatment allocation, c) similar group values at baseline, d) blinded patients, e) blinded care providers, f) blinded assessor, g) avoided or similar cointerventions, h) acceptable compliance, i) acceptable dropout rate, j) similar timing of the outcome assessment in all groups, and k) intention-to-treat analysis. Computer-generated random number tables and use of sealed opaque envelopes were accepted as adequate methods of randomization. Allocation using date of birth, date of admission, hospital numbers, or alternation was not acknowledged as appropriate. Compliance to the interventions had to be 75% or higher. The dropout rate was considered acceptable up to 20% for follow-up < 6 months and up to 30% for follow-up > 6 months. The 11 criteria for assessment of methodological quality were scored with "yes," "no," or (in case of inadequate reports) "unclear." A criterion was given one point for each "yes" score. On the summary quality score (of maximal 11 points), at least 50% (6 of 11) "yes" scores were needed to get a high-quality status.

Authors were contacted in cases where randomization, allocation, or blinding was inadequately described in the publication.

Data extraction. The main characteristics of the included studies were extracted, containing information about sample (age, gender, health status, and setting of the subjects), main characteristics of intervention, and outcomes.

Data synthesis. To investigate the effectiveness of the applied training, the studies reviewed in this article examined strength properties of many different muscle groups and assessed physical performance in a multitude of tests or questionnaires. Because of this heterogeneity, representative outcomes were used for quantitative data analysis. Maximal strength (1RM or MVC), muscle power (peak or average muscle power), and muscle endurance of the knee extensor muscles were chosen because this was the most commonly evaluated muscle group and because of its high relevance for physical function (especially mobility) of older adults. In cases where multiple leg extensor strength tests were performed, dynamic strength results of the leg press were favorably chosen because of its resemblance to functional tasks such as rising from a chair. In addition, the most frequently used functional tests representing mobility (i.e., chair rise, stair climbing, timed up and go, and walking speed) were chosen to identify improvements in physical performance.

The Review Manager version 5.0.16 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008) was used for all analyses. We calculated standardized mean differences (SMD = Hedge' adjusted g, defined as difference between the posttest treatment and the control means divided by the pooled standard deviation) and 95% confidence intervals (CI) for trials with sufficient data (13). When data from multiple studies were available, they were pooled using a random-effects model. Heterogeneity was assessed by using I^2 statistics and 95% CI. A sensitivity analysis was performed to investigate the influence of study quality on the results by excluding studies with very low quality scores (≤4).

There were several articles where insufficient data were published to calculate SMD. In those cases, authors were contacted to obtain the missing data.

Levels of evidence. The evidence was graded as proposed by van Tulder et al. (53). The grades of evidence are defined as follows: strong (consistent findings among multiple high-quality RCT), moderate (consistent findings among multiple low-quality RCT and/or controlled clinical trial (CCT) and/or one high-quality RCT), limited (one low-quality RCT and/or CCT), conflicting (inconsistent findings among multiple trials; RCT and/or CCT), and no evidence from trials (no RCT or CCT).

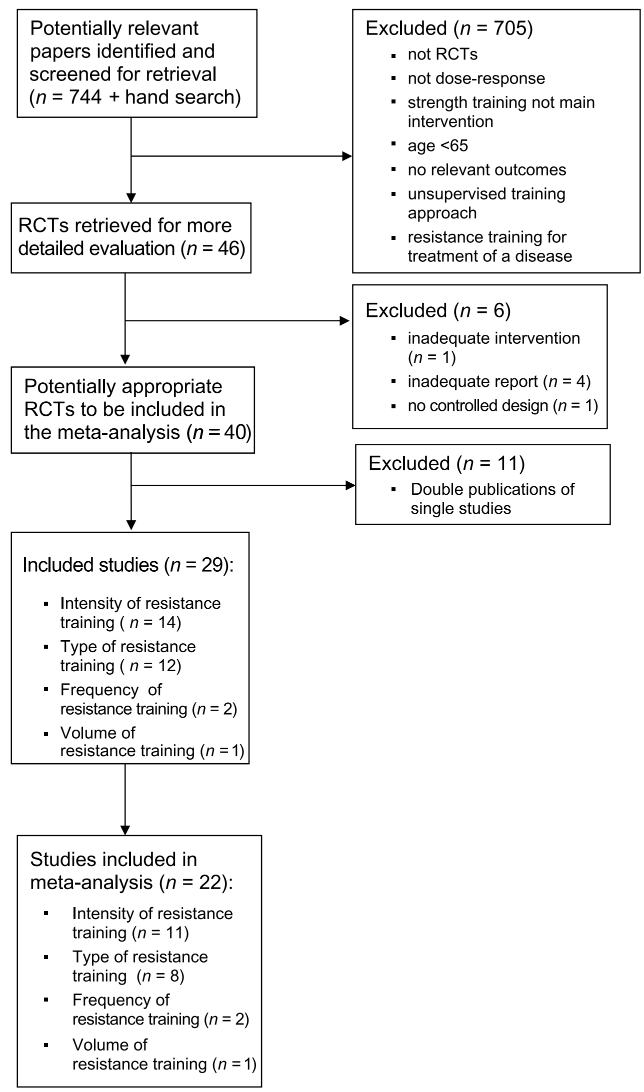
RESULTS

Study Characteristics

A flow diagram of the inclusion and exclusion process is presented in Table 1. The literature search in electronic databases and reference lists identified 46 relevant trials. Six studies were excluded because they did not meet the inclusion criteria (18,21,28,31,34,46), and another 11 trials were double publications of a single trial (11,15,30,37,40, 42,50,55,56,58,59). Twenty-nine studies met the selection criteria and were accepted for inclusion in this review. For 22 of these studies, sufficient data were available to include them in the meta-analysis.

The main characteristics of the 29 included studies are presented in Table 2. A total of 1313 subjects participated in the 29 trials. The mean age of the participants was beween 65 and 80 yr; in the only study with a frail population, the mean age exceeded 80 yr (43). With two exceptions (42,43), all trials included healthy, inactive, community-dwelling subjects. The two most common training doses investigated were "intensity" (14 studies) and "type" of RT (12 studies). Studies investigating the effectiveness of different training intensities usually compared a high-intensity (HI) training (defined as >75% 1RM) with either a low-intensity (LI; <55% 1RM) or a moderate-intensity (MI; 55%–75% 1RM) training. Duration of training interventions predominantly ranged from 8 to 16 wk, seven studies performed 6 months of training, and two trials lasted 1 yr.

TABLE 1. Study flow from identification to final included studies.



The included studies used the following types of RT: progressive resistance training (PRT), power training (PT), eccentric RT (RT with very high loads in the eccentric phase), isometric RT (contraction against a fixed resistance), isokinetic RT (constant movement speed/angular velocity, independent from exerted effort), and functional-task training (FT; repeated training of everyday life tasks with additional weights or against own body weight).

Methodological Quality of Included Trials

The methodological quality scores of included trials are shown in Table 3. A maximum of 11 points was achievable in the quality score. The results range from 2 to 8 points with a mean score of 5.4 ± 1.7 points. Twelve trials had at least 50% yes scores on the van Tulder scale, which were needed for a classification as a trial of high-quality status. Six studies adequately described the method used for randomization; another 12 studies were scored "yes" after contacting the authors; and 11 remained "unclear." The following quality items were poorly described in most cases and consequently achieved low ratings: allocation concealment, blinding, and intention-to-treat analysis.

Quantitative Data Synthesis

A summary of results from the meta-analysis is presented in Table 4. Statistical heterogeneity was present for most of the comparisons. To account for the heterogeneity, a random-effects model was used, and a sensitivity analysis was performed to investigate the effect of study quality on the results. From a clinical and methodological perspective, the studies were comparable, supported by the effect sizes (ES) showing in the same direction.

Maximal muscle strength. ***Training intensity.*** Thirteen studies (6,12,15,16,22,27,29,30,40,43,51,52,57) compared the results of a PRT with different training intensities. For eight trials (n = 214), effect sizes were calculated (Figs. 1 and 2). The pooled data revealed that HI achieved higher ES than MI and LI PRT (SMD [HI vs LI] = 0.88, 95% CI = 0.21–1.55) and that MI attained higher values than LI PRT (SMD [HI vs MI] = 0.62, 95% CI = 0.22–1.03) for the enhancement of maximal strength. Statistical heterogeneity existed for the comparison of HI and LI PRT (I^2 = 74%) but not for the comparison of HI and MI PRT (I^2 = 0%). The sensitivity analysis for study quality led to no essential changes of effects sizes (SMD [HI vs LI] = 0.94, 95% CI = −0.02 to 1.91; SMD [HI vs MI] = 0.84, 95% CI = 0.21–1.47) and heterogeneity.

Effect sizes were also calculated for another two studies (n = 52) with variable training protocols (Table 4). Hunter et al. (29) compared HI PRT with strength training with variable intensities and found no significant group differences. DeBeliso et al. (12) found no significant differences in strength improvement for fixed repetition (9RM) training compared with periodized repetition training (15RM, 9RM, and 6RM).

The protocols of the 13 trials were very similar (three times per week, mostly three sets of 6–14 repetitions). Only the duration of the intervention varied substantially. Also, the samples were very similar in all but one study where subjects were institutionalized and reported as frail (43). The results from this study were not included in data pooling. The strength improvements were substantial for both training groups, with HI being significantly more effective than LI (SMD [HI vs LI] = 1.69, 95% CI = 0.40–2.98).

Type, frequency, and volume. Seven studies (7,10, 24,25,36,44,47) compared different types of training and their effects on maximal strength. Figure 3 shows the pooled data from five studies (n = 140), revealing no significant differences between PT and PRT (SMD [PT vs PRT] = −0.23, 95% CI = −1.42 to 0.96) for improving maximal strength. The effect sizes were heterogeneous (I^2 = 89%). The sensitivity analysis changed the results substantially (SMD [PT vs PRT] = 0.71, 95% CI = 0.02–1.39), but heterogeneity persisted. The comparison between FT and PRT (SMD [FT vs PRT] = −0.16, 95% CI = −0.68 to 0.35) as well as isokinetic eccentric and concentric RT (SMD [ECC vs CONC] = 0.25, 95% CI = −0.83 to 1.33) also revealed no significant differences between the training types.

Two studies (48,14) including 41 subjects investigated the effect of PRT with different training frequencies (once, twice, and thrice a week) on muscle strength. Training two times a week produced higher SMD than a training once weekly (SMD [twice vs once a week] = 1.55, 95% CI = 0.66–2.44). In addition, in the study of Taaffe et al. (48), the group training three times per week was significantly more effective than the group training once a week (SMD [thrice vs once a week] = 2.57, 95% CI = 1.39–3.76) but not more effective than the group training twice weekly (SMD [three vs two times per week] = 0.61, 95% CI = −0.23 to 1.45). However, it is noteworthy that the authors found no significant group differences when results from three strength tests for the lower extremities were combined (48).

One study (19) compared two different training volumes for PRT. Both groups achieved positive adaptations for maximal strength, with no significant group differences for the leg press (SMD [three sets vs one set] = 0.53, 95% CI = −0.23 to 1.29). This was also the case for the isokinetic knee extensor peak torque; however, the authors reported significant group differences for the leg extension exercise in favor of the high-volume group.

Muscle power. Figure 3 shows the pooled data from four studies (7,24,36,44) (n = 99) indicating that PT is more appropriate to increase muscle power than PRT (SMD [PT vs PRT] = 1.66, 95% CI = 0.08–3.24). After excluding low-quality trials, statistical heterogeneity was eliminated, but results favoring PT persisted (SMD [PT vs PRT] = 1.20, 95% CI = 0.63–1.77). de Vos et al. (9) compared different training intensities of PT (20%, 50%, and 80% 1RM). The authors report increases of peak muscle power in all groups, with no significant differences between the groups.

Muscle endurance. There were only few data available to compare the different training doses and their effect on muscle endurance. Vincent et al. (57) (n = 46) reported similar gains in their exercise groups, with no significant difference between HI and LI PRT (SMD [HI vs LI PRT] = 3.30. 95% CI = −9.86 to 16.46). In another study (24) (n = 38), PRT was more effective in enhancing muscle endurance than PT (SMD [PT vs PRT] = −2.24, 95% CI = −3.07 to −1.41). Galvao and Taaffe (19) reported greater increases in muscle endurance for the high-volume group (SMD [3SET vs 1SET] = 1.02, 95% CI = 0.22–1.82).

Mobility-related physical function. ***Training intensity.*** Data from three studies (30,16,56) (n = 139) were available to compare the different training intensities of a PRT to improve physical performance (Figs. 1 and 2). There were no significant group differences for any of the functional tests. Seynnes et al. (43) compared HI and LI PRT in a frail population (n = 16). The functional improvements were substantial for both training groups, with HI being significantly more effective for the walking test (SMD = 1.72, 95% CI = 0.53–2.92) but not for chair rise or stair climbing.

TABLE 2. Characteristics of included studies.

Study	Sample Characteristics	Comparison Groups	Intervention	Relevant Outcomes
Bean et al. (4)	Women, healthy; n = 21 Age: IG = 77.1 yr (SD = 5.7 yr), CG = 78.9 yr (SD = 7.8 yr)	IG: PT CG: PRT	12 wk; three times per week; three sets; 10 reps; nine exercises (based on functional tasks) performed with weighted vests	1RM, peak power SPPB
Beneka et al. (6)	Healthy, sedentary; n = 64 Age: 66–72 yr	IG1: PRT (HI) IG2: PRT (MI) IG3: PRT (LI)	16 wk; PRT; three times per week; three sets; exercises: 3LL HI: 90% 1RM (4–6 reps) MI: 70% 1RM (8–10 reps) LI: 50% 1RM (12–14 reps)	Isokinetic maximal strength
Bottaro et al. (7)	Men, healthy, sedentary; n = 24 Age: IG = 66.6 yr (SD = 5.8 yr), CG = 66.3 yr (SD = 4.8 yr)	IG: PT CG: PRT	10 wk; two times per week; 6–8 reps; three sets; 60% 1RM; exercises: 3LL; 4UL	1RM, peak power Arm curl, chair stand, 8-ft up and go
DeBeliso et al. (12)	Independent; n = 43 Age: 63–83 yr	IG1: RT (FR) IG2: RT (PER) CG: no treatment	18 wk, two times per week FR: 9RM, three sets PER: weeks 1–6 , two sets, 15RM; weeks 7–12, three sets, 9RM; weeks 13–18, 6RM, four sets	1RM
de Vreede et al. (10)	Women, healthy; n = 84 Age: IG1 = 74.7 yr (SD = 3.5 yr), IG2 = 74.8 yr (SD = 4.0 yr), CG = 73.0 yr (SD = 3.2 yr)	IG1: FT IG2: PRT CG: no treatment	12 wk, three times per week, 7–8 (moderate to high) on a 10-point rated perceived exertion scale FT: daily tasks exercises PRT: three to four muscle groups, three sets, 10 reps	MVC, peak muscle power
de Vos et al. (9)	Healthy; n = 112 Age: 69 yr (SD = 6.0 yr)	IG1: PT (HI) IG2: PT (MI) IG3: PT (LI) CG: no treatment	12 wk, two times per week, three sets, 8 reps, exercises: 3LL, 2UL HI: 80% 1RM MI: 50% 1RM LI: 20% 1RM	1RM, peak power, muscle endurance
DiFrancisco-Donoghue et al. (14)	Healthy; n = 18 Age: 65–79 yr	IG1: PRT once a week IG2: PRT two times per week	9 wk, one set, 10–15 reps, 75% 1RM, exercises: 3LL, 3UL	1RM
Fatouros et al. (16)	Men, healthy, sedentary; n = 52 Age: IG1 = 72.4 yr (SD = 3.5 yr), IG2 = 70.3 yr (SD = 4.4 yr), CG = 71.2 yr (SD = 4.1 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: no treatment	24 wk, three times per week, two sets (weeks 1–8), three sets (weeks 9–24), exercises: 3LL, 5UL HI: 80%–85% 1RM (6–8 reps) LI: 50%–55% 1RM (14–16 reps)	1RM TUG, 50-foot walk, stair climbing
Fatouros et al. (15)	Men, healthy, sedentary; n = 58 Age: IG1 = 70.8 yr (SD = 2.8 yr), IG2 = 69.7 yr (SD = 3.8 yr), IG3 = 71.1 yr (SD = 3.6 yr), CG = 69.8 yr (SD = 5.1 yr)	IG1: PRT (HI) IG2: PRT (MI) IG3 PRT (LI) CG: no treatment	24 wk, three times per week, exercises: 3LL, 5UL HI: 80% 1RM (8 reps) MI: 60% 1RM (10 reps) LI: 40% 1RM (14 reps)	1RM
Fielding (16a)	Women, functional deficits, community dwelling; n = 30 Age: 73 yr (SD = 1.0 yr)	IG: PT CG: PRT	16 wk, three times per week, three sets, 8 reps, 70% 1RM, exercises: 2LL	1RM, peak power Balance, chair rise, stair climbing
Galvao and Taaffe (19)	Healthy; n = 32 Age: IG1 = 68.9 yr (SD = 4.8 yr), IG2 = 69.7 yr (SD = 4.4 yr)	IG1: PRT (one set) IG2: PRT (three sets)	PRT, 20 wk, two times per week, 8 RM, exercises: 3LL, 4UL	1RM, muscle endurance Chair rise, 6-m walk, stair climbing
Harris et al. (22)	Healthy; n = 61 Age: 61–85 yr	IG1: PRT (HI) IG2: PRT (MI) IG3: PRT (LI) CG: no treatment	18 wk, two times per week, exercises: 3LL, 5UL HI: 4 × 6RM PRT MI: 3 × 9RM PRT LI: 2 × 15RM PRT	1RM
Henwood et al. (24)	Healthy; n = 67 Age: 65–84 yr	IG1: PT IG2: PRT CG: no treatment	24 wk, two times per week, 8 reps, three sets, exercises: 3LL, 3UL PT: 45%, 60%, and 75% 1RM PRT: 75% 1RM	1RM, muscle endurance, peak power 6-m walk, chair rise, stair climbing
Henwood and Taaffe (25)	Healthy; n = 67 Age: IG1 = 70.7 yr (SD = 5.5 yr), IG2 = 70.2 yr (SD = 5.0 yr), IG3 = 69.3 yr (SD = 4.1 yr), CG = 69.1 yr (SD = 3.6 yr)	IG1: PT IG2: PRT IG3: CB CG: no treatment	8 wk, two times per week, 8 reps, three sets, exercises: 3LL, 3UL, CB: combined functional (once a week) and resistance training (once a week) PT: 45%, 60%, and 75% 1RM PRT: 75% 1RM CB: combined once a week PT, once a week PRT	1RM 6-m walk, chair rise, stair climbing
Hortobagyi et al. (27)	Healthy; n = 30 Age: 72 yr (SD = 4.7 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: no treatment	10 wk, five sets, leg press HI: 80% 1RM (4–6 reps) LI: 40% 1RM (8–12 reps)	1RM, maximal isokinetic + isometric strength, submaximal force control
Hortobagyi and DeVita (26)	Women, healthy; n = 30 Age: 71.4 yr (SD = 4.8 yr)	IG1: ECC IG2: CON (IK) CG: no treatment	1 wk, seven sessions, five to six sets, 9–12 reps, leg press ECC: eccentric overload CON: isokinetic concentric resistance training	3RM, maximal isokinetic + isometric strength
Hunter et al. (29)	Healthy, sedentary; n = 38 Age: IG1 = 67.3 yr (SD = 4.7 yr), IG2 = 65.9 yr (SD = 4.3 yr), CG = 65.9 yr (SD = 4.0 yr)	IG1: PRT (HI) IG2: PRT (VI) CG: no treatment	25 wk, three times per week, two sets, 10 reps, exercises: 4UL, 2LL, 2TRK HI: 80% 1RM VI: 50%, 65%, and 80% 1RM	1RM, isometric MVC Walking, stair climbing, weight-loaded walking
Kalapotharakos et al. (30)	Healthy, sedentary; n = 33 Age: IG1 = 64.6 yr (SD = 5.1 yr), IG2 = 65.7 yr (SD = 4.3 yr), CG = 64.4 yr (SD = 3.4 yr)	IG1: PRT (HI) IG2: PRT (MI) CG: no treatment	12 wk, three times per week, three sets, exercises: 2LL, 4UL, 2TRK HI: 80% 1RM (8 reps) MI: 60% 1RM (15 reps)	1RM 6-m walk, chair rise, stair climbing
Manini et al. (35)	Community dwelling, at risk for subsequent disability; n = 32 Age: 75.8 yr (SD = 6.7 yr)	IG1: PRT IG2: FT IG3: FRT	10 wk, two times per week, 30–45 min, PRT: exercises: 3UL, 3LL FT: five task-specific exercises FRT: 1 d RT, 1 d FT	Average knee extensor work (5 reps) Eight functional tasks, gait speed
Miszko et al. (36)	Community dwelling; n = 50 Age: 72.5 yr (SD = 6.3 yr)	IG1: PT IG2: PRT CG: no treatment	16 wk, three times per week, three sets, 6–8 reps, exercises: 4UL, 5LL PT: power training 40% 1RM PRT: 50%–70% 1RM weeks 1–8, 80% 1RM weeks 9–16	1RM, anaerobic power ADL

Seynnes et al. (43)	Frail, institutionalized; n = 27 Age: 81.5 yr (SD = 1.4 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: placebo-control	10 wk, three times per week, three sets, 8 reps, exercises: LL strengthening using adjustable ankle cuffs HI: 80% 1RM LI: 40% 1RM CG: weight-free cuffs	1RM, muscle endurance Chair rise, stair climbing, 6 min of walking
Signorile (43a)	Women, healthy; n = 28 Age: IG1 = 68.3 yr (SD = 1.4 yr), IG2 = 68.7 yr (SD = 1.6 yr), CG = 69.01 yr (SD = 1.8 yr)	IG1: PT (IK) IG2: PRT (IK) CG: placebo-control	12 wk, three times per week, exercises: isokinetic knee extension/flexion PT: isokinetic power training PRT: isokinetic PRT CG: stretching	Average isokinetic power
Signorile et al. (44)	Women, healthy; n = 17 Age: 68.6 yr (SD = 1.0 yr)	IG: PT (IK) CG: PRT (IK)	12 wk, three times per week, exercises: isokinetic knee extension	Peak torque, average power, total work
Symons et al. (47)	Healthy; n = 37 Age: 73 yr (SD = 5.0 yr)	IG1: ECC (IK) IG2: ISO CG: CON (IK)	12 wk, three times per week, three sets, 10 MVC, knee extension	MVC (isometric + isokinetic ecc/conc), conc average power, conc work Step test, 80-m walk test
Taaffe et al. (49)	Women, healthy, moderately active; n = 40 Age: IG = 67.0 yr (SD = 0.2 yr), IG = 67.6 yr (SD = 0.5 yr), CG = 69.6 yr (SD = 1.3 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: no treatment	52 wk, three times per week, three sets, exercises: 4UL, 5LL, 1TRK HI: 80% 1RM (7 reps) LI: 40% 1RM (14 reps)	1RM
Taaffe et al. (48)	Healthy; n = 53 Age: IG1 = 68.5 yr (SD = 3.6 yr), IG2 = 69.4 yr (SD = 3.0 yr), IG3 = 71.0 yr (SD = 4.1 yr), CG = 68.9 yr (SD = 3.6 yr)	IG1: PRT once a week IG2: PRT two times per week IG3: PRT three times per week CG: no treatment	24 wk, three sets, 8 reps, 80% 1RM, exercises: 4UL, 3LL, 1TRK	1RM Chair rise, tandem backward walk
Tsutsumi et al. (51)	Healthy, sedentary; n = 45 Age: 68.8 yr (SD = 5.7 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: no treatment	12 wk, three times per week, three sets, exercises: 2LL, 7UL, 2TRK HI: 75%–85% 1RM (8–12 reps) LI: 55%–65% 1RM (12–16 reps)	10 RM
Tsutsumi et al. (52)	Women, healthy, sedentary; n = 36 Age: 68.5 yr (SD = 6.1 yr)	IG1: PRT (HI) IG2: PRT (MI) CG: no treatment	12 wk, three times per week, two sets, overall 12 exercises (six exercises each session) HI: 75%–85% 1RM (8–10) MI: 55%–65% 1RM (14–16)	1RM
Vincent (57)	Healthy; n = 84 Age: IG = 66.6 yr (SD = 6.7 yr), IG2 = 67.6 yr (SD = 6.3 yr), CG = 71.0 yr (SD = 4.7 yr)	IG1: PRT (HI) IG2: PRT (LI) CG: no treatment	24 wk, three times per week, one set, exercises: 6UL, 6LL, 1TRK HI: 80% 1RM (8 reps) LI: 50% 1RM (13 reps)	1RM, isometric MVC, muscle endurance Stair climbing

IG, intervention group; CG, control group; PT, power training; PRT, progressive resistance training; FT, functional-task training; FRT, functional plus resistance training; FR, fixed repetition; PER, periodized repetition; CB, combined training; CON, concentric; ECC, eccentric; IK, isokinetic; ISO, isometric; HI, high intensity; MI, moderate intensity; LI, low intensity; VI, variable intensity; LL, lower limb; UL, upper limb; TRK, trunk; RM, repetition maximum; MVC, maximal voluntary contraction; SPPB, Short Physical Performance Battery; TUG, timed up and go; ADL, activities of daily living.

TABLE 3. Study quality assessment (van Tulder scale) and quality score.

Author	Randomization	Allocation Concealed	Comparable at Entry	Patient Blinded	Care Provider Blinded	Assessor Blinded	Cointerventions	Compliance	Dropout	Timing Outcome	ITT	Quality Score
Bean et al. (4)	y	y	y	n	u	y	y	y	y	y	n	8
Beneka et al. (6)	u	u	y	u	u	u	y	u	u	y	y	4
Bottaro et al. (7)	y	y	y	y	n	u	y	u	y	y	n	7
DeBeliso et al. (12)	u	u	y	u	u	u	y	y	y	y	n	5
de Vreede et al. (10)	y	u	y	n	n	y	y	y	y	y	n	7
de Vos et al. (9)	y	y	y	y	u	n	y	y	y	y	n	8
DiFrancisco-Donoghue et al. (14)	y	n	n	n	u	u	y	u	u	y	u	3
Fatouros et al. (16)	u	u	y	u	u	u	y	y	y	y	u	5
Fatouros et al. (15)	u	u	y	u	u	u	y	y	y	y	u	5
Fielding et al. (16a)	y	y	y	n	u	y	y	y	y	y	u	8
Galvao and Taaffe (19)	u	u	y	u	u	u	y	y	y	y	n	5
Harris et al. (22)	u	u	y	u	u	u	y	u	u	y	n	3
Henwood et al. (24)	y	n	y	n	n	u	y	u	y	y	n	5
Henwood and Taaffe (25)	u	u	y	u	u	u	y	y	y	y	n	5
Hortobagyi et al. (27)	y	y	u	y	n	n	y	y	y	y	n	7
Hortobagyi and DeVita (26)	y	y	u	y	n	n	y	y	y	y	y	8
Hunter et al. (29)	y	n	u	y	y	y	y	y	y	y	n	8
Kalapotharakos et al. (30)	y	n	y	u	u	y	y	y	y	u	n	6
Manini et al. (35)	n	y	y	n	n	n	y	u	n	y	n	4
Miszko et al. (36)	y	n	u	u	n	n	y	u	n	y	n	3
Seynnes et al. (43)	y	y	y	y	n	n	y	y	y	u	n	7
Signorile et al. (43a)	y	n	n	n	n	y	y	y	y	y	u	6
Signorile et al. (44)	n	n	n	n	n	y	y	u	u	u	u	2
Symons et al. (47)	y	n	y	n	n	n	y	y	y	y	n	6
Taaffe et al. (49)	u	u	y	u	u	u	y	y	n	y	n	4
Taaffe et al. (48)	u	u	y	u	u	u	y	y	y	y	n	5
Tsutsumi et al. (51)	u	u	y	u	u	u	y	u	y	y	n	4
Tsutsumi et al. (52)	u	u	y	u	u	u	y	u	u	y	y	4
Vincent et al. (2002)	y	u	y	u	u	u	y	y	y	u	n	5
												5.41

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TABLE 4. Standardized mean difference (SMD) and 95% confidence intervals (95% CI) for different comparisons and outcome variables.

Treatment	Author	Maximal Strength SMD (95% CI)	Peak Muscle Power SMD (95% CI)	Muscle Endurance SMD (95% CI)	Chair Rise SMD (95% CI)	Stair Climbing SMD (95% CI)	TUG SMD (95% CI)	Walking Speed SMD (95% CI)
INTENSITY								
High- vs moderate-intensity PRT	Fatouros et al. (15)	0.62 (−0.28 to 1.53)						
	Beneka et al. (6)	0.66 (−0.05 to 1.38)						
	Tsutsumi et al. (52)	0.23 (−0.57 to 1.03)						
	Kalapotharakos et al. (30)	1.04 (0.16 to 1.92)			−0.13 (−0.95 to 0.69)	0.34 (−0.49 to 1.16)		0.12 (−0.70 to 0.94)
Pooled effect size		**0.62 (0.22 to 1.03)**						
Test for overall effect		***P* = 0.003**						
HI vs MI PRT (frail population)	Seynnes et al. (43)	1.69 (0.40 to 2.98)			0.19 (−0.80 to 1.17)	0.82 (−0.22 to 1.85)		1.72 (0.53 to 2.92)
High- vs low-intensity PRT	Taaffe et al. (49)	0.21 (−0.84 to 1.26)						
	Fatouros et al. (15)	1.85 (0.79 to 2.91)						
	Beneka et al. (6)	1.25 (0.48 to 2.02)						
	Hortobagyi et al. (27)	0.40 (−0.60 to 1.39)						
	Vincent (57)	0.00 (−0.58 to 0.58)		3.30 (−9.86 to 16.46)		0.57 (−0.02 to 1.16)		
	Fatouros et al. (16)	1.66 (0.91 to 2.41)				0.18 (−0.46 to 0.82)	0.07 (−0.57 to 0.70)	0.05 (−0.59 to 0.68)
Pooled effect size		**0.88 (0.21 to 1.55)**				0.39 (−0.05 to 0.82)		
Test for overall effect		***P* = 0.01**				*P* = 0.08		
Moderate- vs low-intensity PRT	Fatouros et al. (15)	1.23 (0.28 to 2.18)						
	Beneka et al. (6)	0.36 (−0.34 to 1.06)						
Pooled effect size		**0.74 (−0.11 to 1.58)**						
Test for overall effect		***P* = 0.003**						
High- vs variable-intensity PRT	Hunter et al. (29)	−0.62 (−1.38 to 0.14)						
Fixed repetition vs periodized PRT	DeBeliso et al. (12)	−0.07 (−0.80 to 0.65)						
FREQUENCY								
Twice vs once a week	DiFrancisco-Donoghue et al. (14)	1.10 (0.09 to 2.11)						
	Taaffe et al. (48)	2.01 (0.97 to 3.05)						
Pooled effect size		**1.55 (0.66 to 2.44)**						
Test for overall effect		***P* = 0.003**						
Thrice vs once a week	Taaffe et al. (48)	2.57 (1.39 to 3.76)						
Thrice vs twice a week	Taaffe et al. (48)	0.61 (−0.23 to 1.45)						
VOLUME								
Three sets vs one set	Galvao and Taaffe (19)	0.53 (−0.23 to 1.29)		1.02 (0.22 to 1.82)	0.60 (−0.17 to 1.37)	0.72 (−0.06 to 1.49)		0.27 (−0.48 to 1.02)
Type of RT								
Power training vs PRT	Bottaro et al. (7)	−0.05 (−0.94 to 0.83)	1.20 (0.23 to 2.18)		0.43 (−0.46 to 1.33)		0.03 (−0.85 to 0.91)	
	Henwood and Taaffe (25)	0.78 (0.15 to 1.42)			2.94 (2.03 to 3.85)	1.96 (1.20 to 2.72)		0.00 (−0.61 to 0.61)
	Henwood et al. (24)	1.26 (0.56 to 1.96)	1.20 (0.50 to 1.90)	−2.24 (−3.07, −1.41)	1.86 (1.08 to 2.63)	0.61 (−0.05 to 1.26)		−1.26 (−1.96, −0.56)
	Signorile et al. (44)	−8.24 (−11.54, −4.94)	7.26 (4.32 to 10.21)					
	Miszko et al. (36)	0.05 (−0.75 to 0.85)	−0.37 (−1.18 to 0.44)					
Pooled effect size		**−0.23 (−1.42 to 0.96)**	**1.66 (0.08 to 3.24)**		**1.74 (0.39 to 3.10)**	**1.27 (−0.06 to 2.60)**		**−0.62 (−1.85 to 0.62)**
Test for overall effect		***P* = 0.70**	***P* = 0.04**		***P* = 0.01**	***P* = 0.06**		***P* = 0.33**
Functional task vs PRT	de Vreede et al. (10)	−0.16 (−0.68 to 0.35)	0.19 (−0.32 to 0.71)				0.07 (−0.44 to 0.59)	
	Manini et al. (35)							0.08 (−0.77 to 0.94)
Isokinetic resistance training								
Eccentric-only vs concentric only	Symons et al. (47)	0.25 (−0.83 to 1.33)	−0.16 (−1.23 to 0.92)			−0.21 (−1.11 to 0.69)		−0.19 (−1.10 to 0.71)
Eccentric only vs isometric only	Symons et al. (47)	0.23 (−0.86 to 1.33)	0.27 (−0.83 to 1.37)			−0.40 (−1.29 to 0.50)		−0.19 (−1.08 to 0.69)
Isometric only vs concentric only	Symons et al. (47)	0.03 (−0.87 to 0.93)	−0.40 (−1.31 to 0.52)			−0.28 (−1.14 to 0.58)		−0.05 (−0.90 to 0.81)

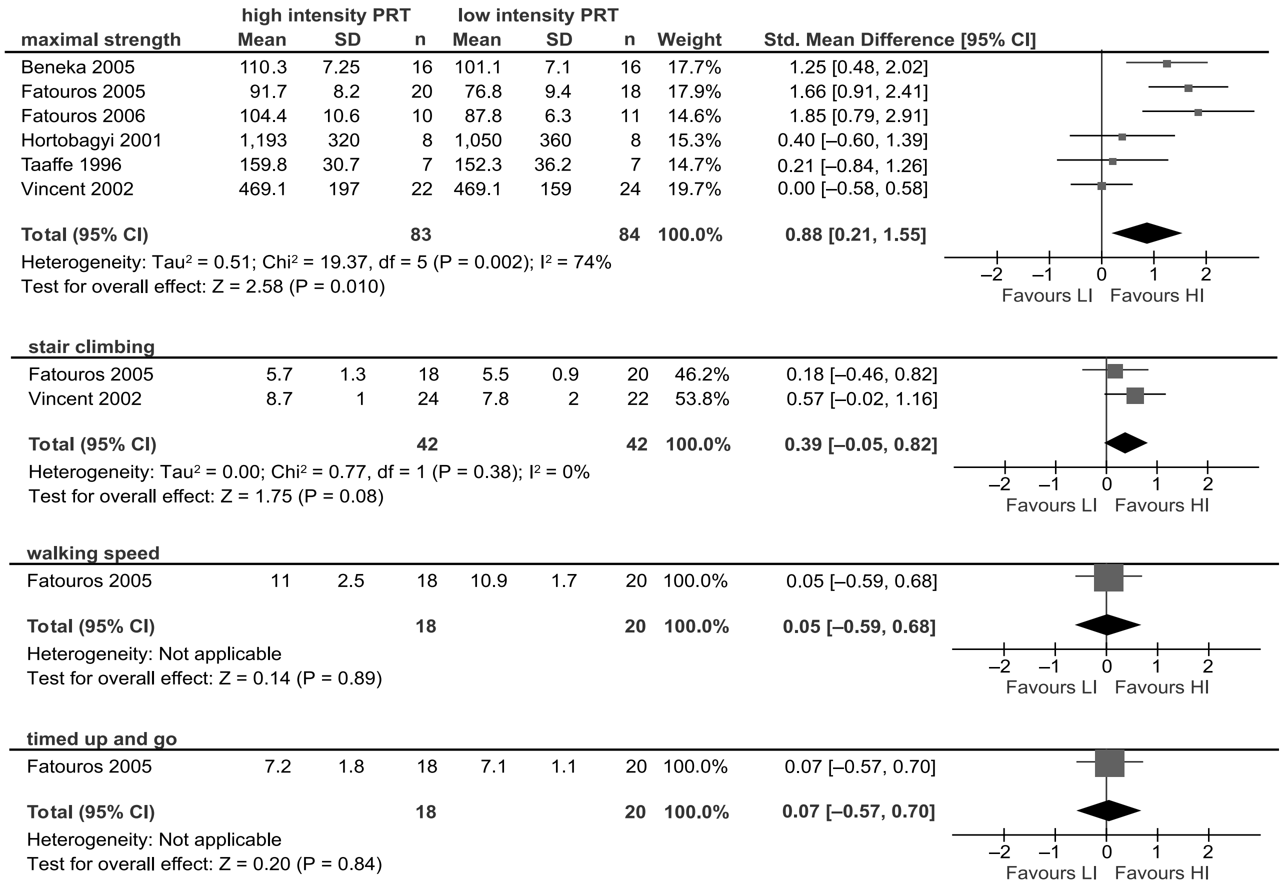

FIGURE 1—Effects of high-intensity (HI) vs low-intensity (LI) progressive resistance training (PRT) on strength and functional outcomes.

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Type, frequency, and volume. Data from three studies (7,25,24) (n = 99) were included to compare the effectiveness of PT and PRT to improve functional parameters in elderly people (Fig. 3). PT was significantly more effective than PRT in improving chair rise (SMD [PT vs PRT] = 1.74, 95% CI = 0.39–3.10) and approached significance for stair climbing ability (SMD "stair" [PT vs PRT] = 1.27, 95% CI = −0.06 to 2.60). However, this was not the case for "walking speed" and the "timed up and go" (TUG). Bean et al. (4) reported significantly higher increases in "chair rise" performance of the PT compared with the PRT group. Miszko et al. (36) evaluated subjects' performance in 16 everyday tasks Continuous Scale Physical Functional Performance (CS-PFP) test and found significantly better results in the PT group.

A comparison between FT and PRT (10,35) revealed no significant group differences (n = 83) for the "TUG" and "walking speed."

There was insufficient data to compare the effects of other types of RT, different training frequency or volume on physical function of older adults.

DISCUSSION

This systematic review summarizes results from RCT that directly compared different training doses and types to enhance strength and function in old and very old adults. The goal was to collect substantial data for all different target groups (healthy, prefrail, and frail) and settings (community dwelling and institutionalized). However, the studies meeting the inclusion criteria mainly targeted healthy, independent, community-dwelling elderly. The results of the quantitative data analysis are summarized in Table 4. Statistical heterogeneity was high for most of the comparisons. However, from a clinical and methodological perspective, the studies seemed comparable.

Training Intensity

High training intensities produced the greatest benefits in maximal muscle strength (optimum: 60%–80% of the 1RM; evidence: strong). These findings coincide with those published in other review articles (32,38). One long-term study (49) found greater strength increases for the HI group in the first 12 wk of intervention but no group differences in the following 8 months. A PRT of variable intensities (50% + 65% + 80% 1RM) achieved similar results compared with HI PRT only (29).

The evidence from two trials (43,57) investigating the effectiveness of different training intensities to improve muscle endurance is conflicting. The differences in study populations (community-dwelling vs frail elderly) and total training volume of the groups might have contributed to this fact.

PRT was effective in enhancing subjects' performance in the functional tasks (i.e., "chair rise," "stair climbing," "timed

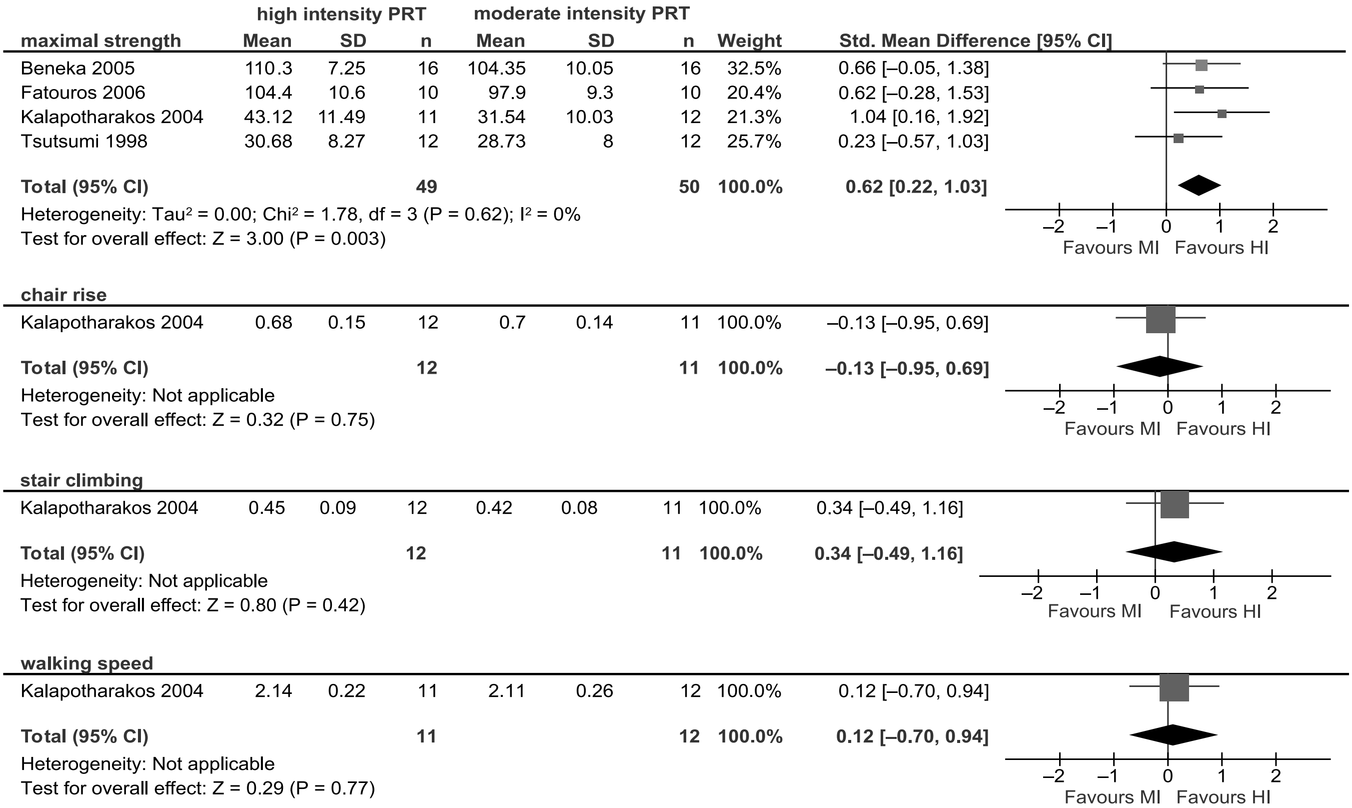

FIGURE 2—Effects of high-intensity (HI) vs moderate-intensity (MI) progressive resistance training (PRT) on strength and functional outcomes.

up and go," and "walking speed"), which were quantified in this meta-analysis. Interestingly, there seem to be no differences in the magnitude of adaptations between HI, MI, or LI PRT (evidence: moderate). There are several possible explanations for the lack of differences in functional improvements for varying training intensities. A strong relationship exists between strength improvements—especially for muscles of the lower extremities—and the functional performance (e.g., walking, stair climbing) of older adults (3,17,32,33,41). However, studies have shown that this relationship is nonlinear. They propose that a threshold exists after which additional strength gains will not lead to further functional improvements (5,8,41). As described above, considerable strength improvements were achieved already by LI and MI PRT. It is possible that these increases in strength were sufficient to reach a threshold for the tested functional tasks. In this case, further enhancement of strength induced by an HI PRT would not lead to better performance in the functional tests and therefore could explain the missing group differences. Furthermore, subjects in most of the studies were sedentary and had little or no experience with RT. It has been reported previously that training adaptations are more substantial for adults at higher ages, especially for those in poor physical condition (17,38,43). It is therefore imaginable that the low baseline status of the subjects included in the summarized studies contributed to the adaptations with relatively low training stimuli. In addition, strength increases are particularly high in the first 10 wk of training, which is not attributed to muscle fiber hypertrophy but more likely to neural and neuromuscular adaptations (20,38). Although high training intensities seem to be necessary to achieve hypertrophy, lower intensities could be sufficient to initiate neuromuscular improvements. Another argument frequently used to explain the missing group differences between LI or MI and HI training groups is the relatively high training volume of LI or MI (10–15 repetitions) compared with HI (4–8 repetitions) exercise (27,43). When the amount of sets and exercises is equal, more repetitions result in a higher total training volume, and this might have a considerable impact on the amount of adaptation.

One study (9,37) compared different intensities of PT. Their conclusions indicate that a very intensive PT has greater effects on maximal strength; however, LI and MI PT are equally appropriate to enhance muscle power and balance.

Type of Training

Power training (PT). In their review articles, Porter (39) and Hazell et al. (23) reported that muscle power shows a higher correlation to functional performance of older adults than muscle strength. They also conclude that PT is more beneficial for enhancing muscle power than PRT and therefore likely to be more effective in improving the functional status. The results of this meta-analysis essentially agree with these findings.

maximal strength	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Bottaro 2007	221.59	41.96	11	223.89	37.73	9	22.1%	–0.05 [–0.94, 0.83]
Henwood & Taaffe 2006	78.4	1.5	21	77.2	1.5	20	23.5%	0.78 [0.15, 1.42]
Henwood 2008	140.3	6.2	19	132.4	6.1	19	23.2%	1.26 [0.56, 1.96]
Miszko 2003	107.65	32.2	11	105.27	53.1	13	22.6%	0.05 [–0.75, 0.85]
Signorile 2005	48.23	4.98	9	92.75	5.29	8	8.6%	–8.24 [–11.54, –4.94]
Total (95% CI)			**71**			**69**	**100.0%**	**–0.23 [–1.42, 0.96]**

Heterogeneity: Tau² = 1.46; Chi² = 34.89, df = 4 (P < 0.00001); I² = 89%
Test for overall effect: Z = 0.38 (P = 0.70)

muscle power	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Bottaro 2007	803.73	164.69	11	618.67	121.91	9	27.6%	1.20 [0.23, 2.18]
Henwood 2008	423.4	15.9	19	403.9	15.9	19	29.1%	1.20 [0.50, 1.90]
Miszko 2003	302.8	18.3	11	309.4	16.5	13	28.5%	–0.37 [–1.18, 0.44]
Signorile 2005	108.94	6.3	9	59.35	6.68	8	14.9%	7.26 [4.32, 10.21]
Total (95% CI)			**50**			**49**	**100.0%**	**1.66 [0.08, 3.24]**

Heterogeneity: Tau² = 2.11; Chi² = 28.37, df = 3 (P < 0.00001); I² = 89%
Test for overall effect: Z = 2.06 (P = 0.04)

chair rise	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Bottaro 2007	25.45	5.61	11	23.33	3.2	9	33.0%	0.43 [–0.46, 1.33]
Henwood & Taaffe 2006	11.4	0.3	20	10.5	0.3	21	32.8%	2.94 [2.03, 3.85]
Henwood 2008	10.99	0.39	19	10.26	0.38	19	34.2%	1.86 [1.08, 2.63]
Total (95% CI)			**50**			**49**	**100.0%**	**1.74 [0.39, 3.10]**

Heterogeneity: Tau² = 1.25; Chi² = 15.05, df = 2 (P = 0.0005); I² = 87%
Test for overall effect: Z = 2.52 (P = 0.01)

stair climbing	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Henwood & Taaffe 2006	4.7	0.1	20	4.5	0.1	21	48.9%	1.96 [1.20, 2.72]
Henwood 2008	4.7	0.21	19	4.57	0.21	19	51.1%	0.61 [–0.05, 1.26]
Total (95% CI)			**39**			**40**	**100.0%**	**1.27 [–0.06, 2.60]**

Heterogeneity: Tau² = 0.79; Chi² = 7.06, df = 1 (P = 0.008); I² = 86%
Test for overall effect: Z = 1.87 (P = 0.06)

walking speed	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Henwood & Taaffe 2006	2.9	0.1	20	2.9	0.1	21	51.0%	0.00 [–0.61, 0.61]
Henwood 2008	2.93	0.07	19	3.02	0.07	19	49.0%	–1.26 [–1.96, –0.56]
Total (95% CI)			**39**			**40**	**100.0%**	**–0.62 [–1.85, 0.62]**

Heterogeneity: Tau² = 0.68; Chi² = 7.01, df = 1 (P = 0.008); I² = 86%
Test for overall effect: Z = 0.98 (P = 0.33)

timed up and go	PT Mean	PT SD	PT n	PRT Mean	PRT SD	PRT n	Weight	Std. Mean Difference [95% CI]
Bottaro 2007	4.96	0.64	9	4.94	0.63	11	100.0%	0.03 [–0.85, 0.91]
Total (95% CI)			**9**			**11**	**100.0%**	**0.03 [–0.85, 0.91]**

Heterogeneity: Not applicable
Test for overall effect: Z = 0.07 (P = 0.95)

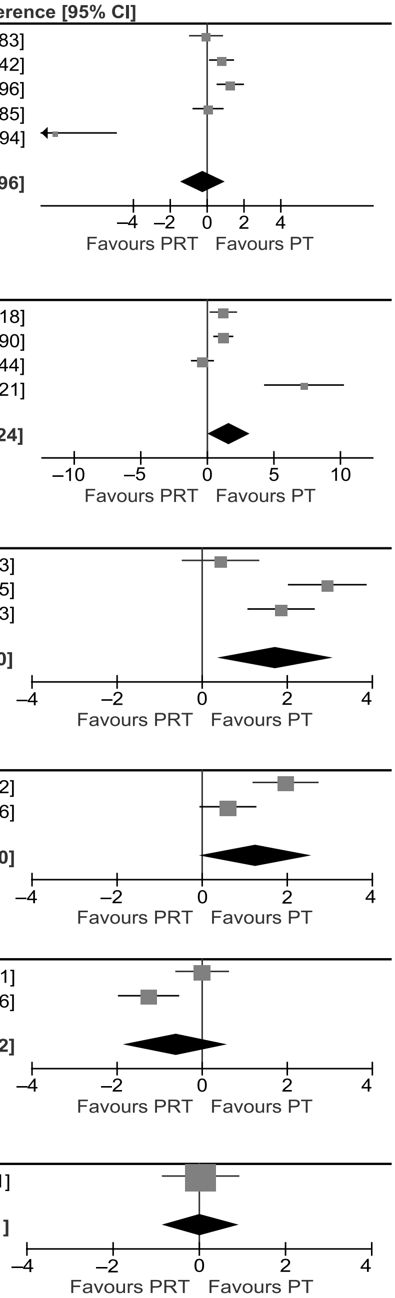

FIGURE 3—Effects of power training (PT) vs progressive resistance training (PRT) on strength and functional outcomes.

PT and PRT seem to enhance maximal muscle strength similarly (evidence: moderate). For improving muscle power, however, PT is more beneficial (evidence: moderate). One study (36) found no significant difference between the PRT and the PT groups for peak and average muscle power gains. However, the authors reported that the PT groups achieved their strength and power gains with a lower absolute workload per session compared with the PRT groups.

As mentioned above, PT is suggested to be more effective for enhancing physical performance of older adults than PRT. The results of our meta-analysis reveal that "chair rise" and "stair climbing" ability improved more with PT compared with PRT (evidence: moderate). However, the little data available showed no difference for the "TUG" and "walking speed" (evidence: limited). Sayers et al. (42) could not reveal significant group differences for any of the assessed functional tasks, which might be due to the small sample size. In summary, the comparison of PT and PRT to improve physical performance leads to inconsistent findings. Therefore, further studies are necessary to clearly point out the benefits of PT.

Eccentric training (ECC). The findings of the two studies (26,47) comparing concentric isokinetic training to an isokinetic training with eccentric overload were inconsistent.

Although the eccentric training group in the study of Symons et al. (47) only performed negative dynamic contractions, the subjects of Hortobagyi and DeVita (26) exercised through the whole range of motion (concentric and eccentric phase) with an overload in the eccentric contraction. As Hortobagyi and DeVita (26) reported significantly greater strength gains with eccentric training, the absence of a concentric phase in the study of Symons et al. (47) might be one possible explanation for the lack of group differences in their trial. As only two RCT for this comparison were identified, it is not possible to provide substantial conclusions (evidence: conflicting).

Functional-task RT. There is good evidence that RT has a positive effect on some aspects of physical performance of older adults, such as stair climbing or walking speed. However, less is known about enhancing the performance in other everyday tasks (3,10,35). Strength training where subjects practice specific everyday tasks against their own body weight or an external resistance is proposed to be very promising (10,35).

Results from two studies included in this meta-analysis showed no advantage of FT compared with PRT for the "TUG" and "walking speed" (evidence: moderate). However, both studies report significantly greater improvements for the FT groups in performing other daily tasks measured (e.g., lifting and carrying a laundry basket). Although the few data could not reveal benefits in the functional tests included in this meta-analysis, it seems that FT is particularly effective to improve performance in ADL of older adults.

Training Frequency and Volume

There is only limited information regarding different training frequencies and volumes of RT with older adults. The results from one study (19) specifically comparing different training volumes indicate that higher training volumes may lead to greater muscle strength and endurance improvements, but lower training volume was sufficient to enhance subjects' physical performance. Two studies directly compared different training frequencies (14,48). The training protocols of the comparison groups were equal. Subjects of all groups performed a PRT with similar intensity, sets, and exercises. The SMD for the maximal knee extensor strength indicate that higher training frequencies lead to greater strength gains. However, when accounting for all tested muscle groups, the authors conclude that training once or twice a week is equally effective to improve strength and also physical performance compared with a training three times a week (evidence: limited).

Strengths and Limitations of This Review

To the best of our knowledge, this is the first systematic review summarizing studies looking specifically at the dose–response relationship of strength training with older adults. For this, we included only those studies that directly compared different training doses by having multiple intervention groups. In contrast to a summary of results from studies with only one intervention group, the conclusions presented in this work are derived from direct comparisons. We consider this as a specific feature of our meta-analysis; however, it implies that the number of underlying studies, and therefore the available information, is limited. Including data from studies investigating the effects of only one specific training dose would be another step to understand the dose–response relationship. We might have failed to identify all studies on this topic as the literature search was not performed in all relevant databases (e.g., CINAHL, EMBASE). It needs to be emphasized that the conclusions made in this review were obtained from data of representative outcomes and therefore might not necessarily apply to either other parameters of strength and function of older adults or different muscle groups or populations of older adults. The methodological quality of the included studies was heterogeneous, and important criteria of the internal validity were not fulfilled in many of the trials. In these cases, the possibility of systematic errors cannot be eliminated.

CONCLUSIONS

Although high training intensities result in greater maximal strength adaptations compared with low and moderate intensities (evidence: strong), this does not necessarily result in greater improvements of functional performance (evidence: moderate). Low and moderate intensities achieve considerable effects not only on function but also on strength measures of older adults (evidence: moderate). PT was the most effective training type to enhance muscle power and some functional tests (i.e., chair rise, stair climbing—evidence: moderate), although the few data for "walking speed" and "TUG" showed no advantages for PT (evidence: limited). No substantial conclusions can be made about potential benefits of other RT types (i.e., functional-task RT, eccentric or isometric RT; evidence: limited). All training types reviewed showed to be securely applicable to the target group of old adults. Independent from the type of RT, performing exercises task-specific (ADL-specific) is a promising strategy to maximize the effect on functional performance of the elderly. No substantial conclusions can be made about the most adequate volume or frequency to improve either of the main outcomes (evidence: limited). Some authors report considerable effects already with low training volume (one set) and frequencies (once a week). Considering the greater regeneration time and the decreased mobility of older adults, low frequencies seem to be more practical. In general, there is a good body of evidence regarding the most adequate intensity and type of RT for improving muscle strength measures. Further research is needed to provide more substantial conclusions regarding the most adequate dose and type of RT for improving physical performance of older adults.

As previously mentioned, the subjects in most included trials were healthy, community-dwelling, older adults. Therefore, the findings summarized above cannot be directly applied to other populations, such as frail elderly. Although there is a fair amount of work showing that RT is safe and effective even for very old and frail elderly (17,32,36,43), the dose–response relationship remains unclear for this population.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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