

## Review Article

# Systematic Review of Progressive Resistance Strength Training in Older Adults

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**Background.** The aim of this systematic review was to quantify the effectiveness of progressive resistance strength training (PRT) to reduce physical disability in older people.

**Methods.** Randomized controlled trials were identified from searches of relevant databases and study reference lists and contacts with researchers. Two reviewers independently screened the trials for eligibility, rated their quality, and extracted data. Only randomized controlled trials utilizing PRT as the primary intervention in participants, whose group mean age was 60 years or older, were included. Data were pooled using fixed or random effect models to produce weighted mean differences (WMD) and 95% confidence intervals (CI). Standardized mean differences (SMD) were calculated when different units of measurement were used for the outcome of interest.

**Results.** 62 trials ( $n = 3674$ ) compared PRT with a control group. 14 trials had data available to allow pooling of disability outcomes. Most trials were of poor quality. PRT showed a strong positive effect on strength, although there was significant heterogeneity (41 trials [ $n = 1955$ ], SMD 0.68; 95% confidence interval [CI] 0.52, 0.84). A modest effect was found on some measures of functional limitations such as gait speed (14 trials [ $n = 798$ ], WMD 0.07 meters per second; 95% CI 0.04, 0.09). No evidence of an effect was found for physical disability (10 trials [ $n = 722$ ], SMD 0.01; 95% CI -0.14, 0.16). Adverse events were poorly investigated, but occurred in most studies where they were defined and prospectively monitored.

**Conclusions.** PRT results in improvements to muscle strength and some aspects of functional limitation, such as gait speed, in older adults. However, based on current data, the effect of PRT on physical disability remains unclear. Further, due to the poor reporting of adverse events in trials, it is difficult to evaluate the risks associated with PRT.

MUSCLE weakness is associated with reduced walking speed (1) and an increased risk of disability (2) and falls (3) in older people. However, muscle strength can be improved in these individuals, particularly if their muscles are significantly overloaded by training exercises (4). The most frequently used approach to this form of exercise is progressive resistance training (PRT), since participants work against an external force that is increased as strength increases. Despite evidence of benefit from PRT on strength, there is uncertainty about whether these effects translate into changes in substantive clinical outcomes such as prevention of falls and a reduction in physical disability. Most studies have been under-powered to determine the effects of PRT on these outcomes or have included PRT as a component of a multifaceted intervention. Although many recent guidelines and reviews have provided an assessment of the effectiveness of PRT (5–7), we wished to provide a systematic synthesis of the evidence from randomized clinical trials. In particular, we wished to determine whether PRT, as a single exercise intervention, improves strength, functional limitations, and physical disability in older adults.

## METHODS

### Inclusion Criteria

We included only randomized controlled clinical trials of participants who were older adults (i.e., group mean age of 60 years or older) and where PRT was used as the primary intervention. PRT was defined as a strength-training program in which participants exercised their muscles against an external force that was set at a specific intensity for each participant, and this resistance was adjusted throughout the training program. Studies that included other forms of training as part of an exercise program (and not simply part of the warm-up or cool-down) were excluded.

The primary outcome was physical disability, assessed as a continuous measure, and defined conceptually according to the Nagi model as “a limitation in the performance of socially defined roles and tasks (self-care, work, etc.)” (8). Subsequent to undertaking this review, however, the World Health Organization’s International Classification of Functioning, Disability and Health (ICF) was released (9), where disability is defined as an umbrella term for impairments, activity limitations, and participation restrictions.

Thus, according to the ICF, the outcome measures evaluated in this review fall under the domains of impairments, limitations in simple activities (i.e., similar to functional limitations in Nagi's system), and limitations in complex activities (i.e., similar to some aspects of disability in Nagi's model). We included self-report measures of physical disability based on a variety of instruments that were not restricted to basic activities of daily living (ADL) such as the Barthel Index (10), but also covered wider physical domains included in health-related quality of life (HRQOL) such as the Physical Function (PF) domain of the 36-item short-form questionnaire (SF-36) (11). Secondary outcomes were also assessed according to continuous measures that covered the domains of physical impairment (i.e., strength and aerobic capacity) and functional limitations (i.e., balance, chair-rise, gait speed, timed up-and-go). Other secondary outcomes that were assessed as dichotomous endpoints were falls, adverse events, admission to hospital, and death.

### Search Strategy

The following databases were searched: MEDLINE (1966–February 1, 2002), EMBASE (1980–February 1, 2002), CINAHL (final search February 1, 2002), Sports Discus (1948–February 1, 2002), PEDRO (final search February 1, 2002), Digital Dissertations (final search February 1, 2002); the Cochrane Controlled Trials Register (final search February 1, 2002) and the registers of the Cochrane Musculoskeletal Injuries Group and the Rehabilitation Field (final search August 30, 2002). Reference lists for all identified studies were inspected for other suitable studies, and relevant review articles and conference proceedings were screened. Experts in the field were contacted for information regarding unpublished trials. No language restrictions were applied.

### Quality Assessment and Data Extraction

Two reviewers (N.K.L. and C.M.S.) screened the titles and abstracts from the database searches to identify potentially relevant trials. After complete copies of the articles were obtained, they used the previously defined inclusion criteria to independently select trials and assess quality. During the quality assessment, the reviewers were masked to the authors, institution, journal title, and trial results. They also independently extracted the data. If these data were not reported in a form that enabled quantitative pooling, the authors were contacted for additional information. If the authors could not be contacted or if the information was not available, the trial was not included in the pooling for that specific outcome.

### Quantitative Synthesis

Several factors influenced decisions about whether data should be pooled for a particular outcome and what the most appropriate methods were to be used in the analyses. These factors and our approach to synthesizing these data are described below. MetaView version 4.1 was used for all analyses (12).

*Clinical and statistical heterogeneity.*—Clinical heterogeneity occurs when the study results differ due to patient characteristics, dose response, or preexisting conditions, while statistical heterogeneity occurs when the results are too different to combine via a particular statistical model, as the results violate the underlying assumptions of that statistical model. In some cases, controlling (or removing) clinical heterogeneity may also remove statistical heterogeneity, but the converse is not usually true.

Although several tests of statistical heterogeneity exist, these are known to have low power. For this review, therefore, a conservatively high significance threshold ( $p < .1$ ) was used in order to rule out the possibility of statistical heterogeneity influencing the results.

*Fixed and random effects.*—Either fixed or random effects models can be used in the analysis of pooled data. For the fixed effect approach, it is assumed that random sampling error is the only source of variability around the summary effect size. That is, the estimated pooled effect is assumed to reflect a consistent true effect across studies (13). In general, for a fixed effect method, the individual study estimates are combined using weights, with the weights based on the inverse of the variance of the effect size for that study. For a random effects model, the underlying assumption is that the true effect in different studies is randomly positioned about some central value (14). In general, random effects methods also use weights, but the weights are the inverse of the combined “within” and “between” study variation. This approach attempts to account for the statistical heterogeneity between the studies included in a meta-analysis. In this review, we first performed a test of statistical heterogeneity for each outcome. If this was minimal ( $p < .1$ ), a fixed effects meta-analysis was performed. On the other hand, if there was substantial statistical heterogeneity, we searched for possible explanations by conducting subgroup analyses, and, if none were identified, a random effects model was used albeit with cautious interpretation.

*Type of outcome.*—Different methods were required in the pooling of data, depending on whether the outcome of interest was dichotomous or continuous, and for continuous outcomes, if the same units were used for all measures or not. For continuous outcomes that used different measurement units, standardized units (i.e., standardized mean differences [SMD]) were created, with Hedges adjusted  $g$ , which is very similar to Cohen's  $d$ , but includes an adjustment for small sample bias (13). For the continuous outcomes that used similar units, a weighted mean difference (WMD) was computed. Relative risks and 95% confidence intervals (CI) were calculated for dichotomous outcomes.

*Additional analyses.*—Sensitivity and subgroup analyses (specified a priori) were conducted if the data were sufficient to explore the effect of differences in trial quality, PRT dose, and the health status of participants. In addition, a sensitivity analysis was conducted to determine the effect of removing one of the largest trials.

## RESULTS

Initial searches identified 186 trials that appeared eligible for inclusion, but 120 of these did not meet the study inclusion criteria. The main reasons for exclusion were: the study used a combination of exercise interventions (i.e., not PRT alone); the program did not use a standard approach to PRT; the participants were not elderly (i.e., group mean age was not 60 years or older); or the study was not a randomized controlled trial (Table 1). Of the 66 remaining trials, 4 trials were not included in this version of the review because participants were not randomized to a nonexercise control group [i.e., PRT was compared with aerobic training (15–17) or different intensities of PRT were compared with control (18)]. Therefore, this review is based on 62 trials with 3674 participants (Table 2).

The participants in most of the included studies (35 trials) were healthy, community-dwelling older people with no functional limitations (Table 2). In the remaining 27 studies, the participants had a health problem or functional limitation, and were residing in a hospital or residential-care setting. Fourteen of these 27 trials included older people with a variety of specific medical conditions, including osteoarthritis (19–22), peripheral arterial disease (23,24), acute stroke (25), congestive heart failure (26,27), chronic airflow limitation (28), depression (29), low bone mineral density (30), chronic renal insufficiency (31), and recent coronary artery bypass graft surgery (32). In 13 other studies, the trials recruited participants without a single specific health problem, rather they were considered to be frail and/or had a functional limitation on clinical grounds (33–44). Four of these studies were undertaken with participants who were residents of a long-term residential care facility such as a rest home or nursing home (36,40,41,44), while two studies were undertaken in participants while they were receiving care in hospital (34,45).

Most studies included both men and women, but 5 trials included only men (32,41,46–48) and 13 trials included only women (4,26,30,42,49–57). In 29 studies, the mean or median age of the participants ranged from 60 to 69 years, while in 22 studies, the figure was 70 to 79 years, and in 10 studies it was 80 years or more. One trial did not report the mean age. Most training programs took place in the setting of a gym or clinic, where the sessions could be closely supervised. Seven studies were undertaken entirely in the home (19,35,37–40,58), while 7 additional studies mixed the training between home and a gym or clinic (20,42,43,53,59–61).

Most trials (43 trials) evaluated PRT that had a high training intensity and usually involved use of specialized exercise machines. Twelve trials used low-to-moderate intensity PRT, mainly with elastic tubing or bands. In almost all of the trials, PRT was performed two to three times weekly, but there was wide variation in the frequency and duration of the exercises. Although most programs (35 trials) continued PRT for 8 to 12 weeks, the duration ranged from 2 weeks to 78 weeks, and the number of exercises performed in each session varied from 1 to more than 14.

Table 1. Reasons for Exclusion of Trials

| Reason for Exclusion  | Trials      |
|---|-------------|
| Not an RCT  | (18,76–128) |
| Mean age <60 years  | (129–143)   |
| Combined program—not PRT alone  | (144–188)   |
| Training not considered to be PRT   | (189–197)   |
| Serious problems with internal validity (i.e., problems with randomization or greater than 30% of participants dropped out) | (198,199)   |
| No control group (compared PRT with aerobic exercise)   | (15–17)     |
| Not randomized to PRT or control group (randomized to different PRT intensities)  | (18)        |

Notes: Numbers in parentheses are reference numbers.

RCT = randomized controlled trial; PRT = progressive resistance training.

### Trial Methodological Quality

The trials were evaluated to determine whether efforts were made to minimize bias by utilizing design features known to improve internal validity. Thirteen studies stated that they used a blinded assessor for all outcome measures (20,21,25,35,37,39–41,43,53,58,62,63). Five additional studies used a blinded outcome assessor for some, but not all, outcome assessments (19,26,29,31,36). Eighteen studies used an attention control program (19–21,25,26,29,31,35,36,38,40,41,44,50,60,61,63,64). In three of these studies, the control group received “sham exercise” programs (19,26,31). Twenty studies provided information about the method of randomization, which suggested probable concealment of patient/treatment allocation and/or that randomization lists were generated without bias (19,21,25,28,29,34–37,40,42,45–47,49,54,62,63,65,66). Nine studies stated that they used intention-to-treat analysis (19,20,25,26,35,36,52,62,63), but several studies did not include people who adhered poorly to the exercise program (61) or experienced adverse responses (48) in the analyses. There were more dropouts in the PRT group (219 PRT vs 148 control).

### Effects of PRT—Impairment Measures

To minimize clinical heterogeneity, data were pooled from one muscle group, the leg extensors, as this was the most frequently evaluated large muscle group in trials of PRT. Table 3 shows the pooled results from 41 trials of PRT compared with a control group involving 1955 participants. There was a significant moderate-to-large beneficial effect of PRT on strength (*SMD* 0.68; 95% *CI* 0.52, 0.84). However, there was significant statistical heterogeneity apparent in these data (Figure 1). Table 3 also shows that there was no clear effect of PRT on aerobic capacity (*SMD* 0.13; 95% *CI* –0.02, 0.27) based on 777 participants (20,23–29,32,37,48,62,65,67–69). However, a different pattern emerged when these data were pooled separately for this outcome by the measures of maximum aerobic capacity ( $\text{VO}_2$  max, ml/kg/min) (20,23,26,27,32,48,62,65,67,68,70) and the Six-Minute Walk Test (meters) (24,26–29,37). There was no clear effect on  $\text{VO}_2$  max alone, but PRT had a significant moderate effect on the walk test (*WMD* 53.7 meters; 95% *CI* 27.0, 80.4), perhaps suggesting that the latter test provides a more relevant assessment of aerobic function in older people.

Table 2. Characteristics of Included Trials

| Study                     | Number Included in Review* | Mean Age (y)** | Health and/or Functional Status       | Exercise Intensity | Exercise Duration (wk) | Number of Exercises                | Exercise Setting |
|---------------------------|----------------------------|----------------|---------------------------------------|--------------------|------------------------|------------------------------------|------------------|
| Ades 1997 (67)            | 24                         | 70             | Healthy                               | High               | 12                     | 4 UL, 3 LL                         | Gym              |
| Baker 2001 (19)           | 46                         | 68             | Osteoarthritis                        | Moderate-high      | 16                     | 5 LL (plus 2 functional exercises) | Home based       |
| Balagopal 2001 (200)      | 20                         | 71             | Healthy                               | High               | 12                     | 4 UL, 3 LL                         | Gym              |
| Bermon 1999 (201)         | 32                         | 70             | Healthy                               | High               | 8                      | 1 UL, 2 LL                         | Gym              |
| Brandon 2000 (72)         | 85                         | 72             | Healthy                               | High               | 16                     | 3 LL                               | Gym              |
| Buchner 1997 (62)         | 55                         | 74             | Functional limitation                 | High               | 24–26                  | 2 UL, 9 LL, 1 Tr                   | Gym              |
| Castaneda 2001 (31)       | 26                         | 65             | Chronic renal insufficiency           | High               | 12                     | 2 UL, 3 LL                         | Gym              |
| Chandler 1998 (37)        | 100                        | 78             | Functional limitation                 | Low-moderate       | 10                     | 8 LL                               | Home             |
| Charette 1991 (4)         | 27                         | 69             | Healthy                               | High               | 12                     | 7 LL                               | Gym              |
| Collier 1997 (202)        | 39                         | 65–85 (range)  | Healthy                               | High               | 10                     | 5 UL, 2 LL                         | Gym              |
| Damush 1999 (50)          | 71                         | 68             | Healthy                               | Low-moderate       | 8                      | 4 UL, 3 LL                         | Gym              |
| Donald 2000 (34)          | 58                         | 81             | Hospitalized                          | High               | NR                     | 2 LL                               | Hospital         |
| Ettinger 1997 (20)        | 295                        | 68             | Osteoarthritis, functional limitation | Moderate-high      | 78                     | 4 UL, 5 LL, 1 Tr                   | Gym + home       |
| Fiatarone 1994 (36)       | 51                         | 87             | Frail                                 | High               | 10                     | 2 LL                               | Gym              |
| Fiatarone 1997 (38)       | 34                         | 82             | Frail                                 | High               | 16                     | 11 (UL, LL)                        | Home             |
| Flynn 1999 (51)           | 29                         | 73             | Healthy                               | High               | 10                     | 8 LL                               | Gym              |
| Hagerman 2000 (48)        | 22                         | 64             | Healthy                               | High               | 16                     | 3 LL                               | Gym              |
| Haykowsky 2000 (203)      | 22                         | 68             | Healthy                               | High               | 16                     | 5 UL, 3 LL                         | Gym              |
| Hennessey 2001 (204)      | 16                         | 71             | Frail                                 | Moderate-high      | 25                     | 11 (UL, LL)                        | Gym              |
| Hiatt 1994 (23)           | 19                         | 67             | Peripheral arterial disease           | High               | 12                     | 6 LL                               | Gym              |
| Hortobagyi 2001 (205)     | 30                         | 72             | Healthy                               | High + low         | 10                     | 1 LL                               | Gym              |
| Jette 1996 (58)           | 102                        | 71             | Healthy                               | Low-moderate       | 12–15                  | 10 (UL, LL, Tr)                    | Home             |
| Jette 1999 (39)           | 215                        | 75             | Functional limitation                 | Low-moderate       | 26                     | 11 (UL, LL, Tr)                    | Home             |
| Jones 1994 (53)           | 46                         | 67             | Healthy                               | Moderate           | 16                     | 7 LL                               | Gym + home       |
| Jubrias 2001 (206)        | 26                         | 69             | Healthy                               | High               | 24                     | 1 LL, 2 UL                         | Gym              |
| Judge 1994 (63)           | 55                         | 80             | Healthy                               | Moderate-high      | 12                     | 6 LL                               | Gym              |
| Kerr 2001 (207)           | 84                         | 60             | Healthy                               | High               | 104                    | 4 UL, 4 LL                         | Gym              |
| Latham 2001 (45)          | 20                         | 81             | Hospitalized                          | High               | 2                      | 1 LL                               | Hospital         |
| Latham 2003 (35)          | 243                        | 79             | Frail                                 | Moderate-high      | 10                     | 1 LL                               | Home             |
| Maiorana 1997 (32)        | 31                         | 60             | 3 Months post-CABG                    | Moderate-high      | 10                     | 7 UL, 4 LL, 1 Tr                   | Gym              |
| Maurer 1999 (21)          | 113                        | 66             | Osteoarthritis                        | High               | 8                      | 1 LL                               | Gym              |
| McCartney 1995 (64)       | 142                        | 64             | Healthy                               | High               | 42                     | 3 UL, 3 LL, 1 Tr                   | Gym              |
| McGuigan 2001 (24)        | 20                         | 68             | Peripheral arterial disease           | High               | 24                     | UL, LL, Tr                         | Gym              |
| McMurdo 1995 (40)         | 86                         | 82             | Functional limitation                 | Low-moderate       | 26                     | 24 (UL, LL, Tr)                    | Home             |
| Mihalko 1996 (44)         | 58                         | 83             | Healthy                               | High               | 8                      | 5 UL                               | Gym              |
| Moreland 2001 (25)        | 133                        | 69             | Stroke                                | NR                 | NR                     | NR                                 | Hospital         |
| Nelson 1994 (52)          | 40                         | 61             | Healthy                               | High               | 52                     | 2 LL, 2 Tr                         | Gym              |
| Newnham 1995 (41)         | 30                         | 82             | Functional limitation                 | High               | 12                     | UL, LL, Tr                         | Gym              |
| Nichols 1993 (54)         | 36                         | 67             | Healthy                               | High               | 24                     | 4 UL, 2 LL, 1 Tr                   | Gym              |
| Parkhouse 2000 (30)       | 22                         | 68             | Low bone mineral density              | High               | 32                     | 9 LL                               | Gym              |
| Perrig-Chiello 1998 (208) | 46                         | 73             | Healthy                               | NR                 | 8                      | NR                                 | Gym              |
| Pollock 1991 (65)         | 36                         | 72             | Healthy                               | High               | 26                     | 5 UL, 2 LL, 3 Tr                   | Gym              |
| Pu 2001 (26)              | 16                         | 77             | Heart failure                         | High               | 10                     | 2 UL, 2 LL                         | Gym              |
| Rall 1996 (209)           | 14                         | 70             | Healthy                               | High               | 12                     | 1 UL, 2 LL, 2 Tr                   | Gym              |
| Rhodes 2000 (55)          | 44                         | 69             | Healthy                               | High               | 52                     | 3 UL, 3 LL                         | Gym              |
| Sartorio 2001 (210)       | 30                         | 73             | Healthy                               | High               | 16                     | 4 UL, 2 LL                         | Gym              |
| Schilke 1996 (22)         | 20                         | 65             | Osteoarthritis                        | High               | 8                      | 1 LL                               | Gym              |
| Schlicht 1999 (71)        | 24                         | 72             | Healthy                               | High               | 8                      | 6 LL                               | Gym              |
| Simpson 1992 (28)         | 34                         | 73             | Chronic airflow limitation            | High               | 8                      | 1 UL, 2 LL                         | Gym              |
| Singh 1997 (29)           | 32                         | 71             | Depressed                             | High               | 10                     | 2 UL, 3 LL                         | Gym              |
| Siplia 1996 (56)          | 27                         | 77             | Healthy                               | High               | 18                     | 4 LL                               | Gym              |
| Skelton 1995 (42)         | 47                         | 80             | Healthy                               | Low-moderate       | 12                     | 3 UL, 6 LL                         | Gym + home       |
| Skelton 1996 (59)         | 20                         | 81             | Functional limitation                 | Low-moderate       | 8                      | 2 UL, 6 LL                         | Gym + home       |
| Taaffe 1996 (57)          | 36                         | 68             | Healthy                               | High + low         | 52                     | 3 LL                               | Gym              |
| Taaffe 1999 (211)         | 46                         | 71             | Healthy                               | High               | 24                     | 4 UL, 3 LL                         | Gym              |
| Topp 1993 (60)            | 63                         | 70             | Healthy                               | Low-moderate       | 12                     | 6 UL, 6 LL                         | Gym + home       |

Table 2. Characteristics of Included Trials (Continued)

| Study                 | Number Included in Review* | Mean Age (y)** | Health and/or Functional Status | Exercise Intensity | Exercise Duration (wk) | Number of Exercises | Exercise Setting |
|-----------------------|----------------------------|----------------|---------------------------------|--------------------|------------------------|---------------------|------------------|
| Topp 1996 (61)        | 61                         | 72             | Healthy                         | Low-moderate       | 14                     | 11 (UL, LL, Tr)     | Home             |
| Tsutsumi 1997 (70)    | 42                         | 68             | Healthy                         | High + low         | 12                     | 7 UL, 2 LL, 2 Tr    | Gym              |
| Tyni-Lenne 2001 (212) | 24                         | 63             | Heart failure                   | Low-moderate       | 8                      | Many UL, LL         | Gym              |
| Vincent 2002 (66)     | 62                         | 68             | Healthy                         | High               | 26                     | 6 UL, 5 LL, 2 Tr    | Gym              |
| Westhoff 2000 (43)    | 26                         | 76             | Functional limitation           | Low                | 10                     | 9 LL                | Gym + home       |
| Wood 2001 (213)       | 16                         | 45             | Healthy                         | High               | 12                     | 5 UL, 3 LL          | Gym              |

Notes: \*Number excludes trial groups that do not meet this review's inclusion criteria (i.e., aerobic training groups).

\*\*When overall age not reported, mean age for PRT group reported.

UL = upper limb; LL = lower limb; Tr = trunk; NR = not reported; gym + home = program performed at both settings; high + low = different groups performed PRT at different intensities; PRT = progressive resistance training; CABG = coronary artery bypass graft.

### Effects of PRT—Functional Limitation Measures

No clear effect was found for PRT on measures of standing balance (*SMD* 0.11; 95% CI  $-0.03, 0.25$ ) among 789 participants (35,37,39,41–43,45,59,60,62,63,71). Similar effect estimates were found when only two measures (i.e., timed position-holding and balance during more complex activities such as the Berg Balance test) were examined separately (Table 3). However, for the chair-rise (i.e., the time to stand up from a sitting position), a significant, moderate-to-large beneficial effect of PRT was observed (*SMD*  $-0.67$ ; 95% CI  $-1.31, -0.02$ ), although this was derived from only a small amount of data ( $n = 185$ ) (29,59,63,72). The two measures of walking speed used, gait speed (higher scores indicate faster mobility) and timed walk (i.e., time to walk a set distance, higher scores indicate slower mobility), were analyzed separately (Table 3). PRT showed a modest significant beneficial effect on gait speed ( $n = 798$ ) with *WMD* 0.07 (95% CI 0.04, 0.09) meters per

second (Figure 2) (27,29,35–37,41,42,56,60–63,71,72). Although a nonsignificant effect (*WMD* 0.77 s, 95% CI  $-0.65, 2.2$ ; lower score indicates better performance) was found for the timed walk ( $n = 81$ ), this was based on very limited data. When data for the Timed Up-and-Go Test (i.e., time to stand, walk 3 meters, turn, and return to sitting) were pooled ( $n = 494$ ) (35,39,41,43,45,59), the estimate was consistent with either no effect or a small, nonsignificant benefit (*WMD*  $-1.2$  s, 95% CI  $-2.8, 0.4$ ; lower score indicates better performance).

### Effects of PRT—Physical Disability Measures

A total of 14 trials reported disability outcomes. Two analyses were conducted for physical disability because 10 studies ( $n = 722$ ) (19,23,25,29,34,35,37,50,62,70) used measures where higher scores indicated less disability (Figure 3), 6 studies ( $n = 559$ ) (19,20,22,29,39,43) used measures where higher scores indicated greater disability,

Table 3. Summary of Main Results

| Outcome                                | Number of Trials | Number of Participants | Heterogeneity ( <i>p</i> Value) | Model  | Effect Size (95% CI)                        | Effect Estimate ( <i>p</i> Value) |
|--|------------------|------------------------|---------------------------------|--------|---|-----------------------------------|
| Strength (leg extensors)               | 41               | 1955                   | <.0001                          | Random | <i>SMD</i> 0.68 (0.52, 0.84)                | <.0001                            |
| Aerobic capacity                       |                  |                        |                                 |        |   |                                   |
| Overall                                | 16               | 777                    | .91                             | Fixed  | <i>SMD</i> 0.13 ( $-0.02, 0.27$ )           | .08                               |
| VO <sub>2</sub> maximum                | 11               | 496                    | 1.0                             | Fixed  | <i>WMD</i> 0.47 ml/kg/min ( $-0.03, 0.97$ ) | .07                               |
| 6-Minute walk test                     | 6                | 212                    | .86                             | Fixed  | <i>WMD</i> 53.7 m (27.0, 80.4)              | <.0001                            |
| Balance                                |                  |                        |                                 |        |   |                                   |
| Overall                                | 12               | 789                    | .22                             | Fixed  | <i>SMD</i> 0.11 ( $-0.03, 0.25$ )           | .11                               |
| Timed Position Hold                    | 5                | 187                    | .8                              | Fixed  | <i>SMD</i> 0.16 ( $-0.13, 0.45$ )           | .3                                |
| Complex Activities                     | 7                | 602                    | .054                            | Random | <i>SMD</i> 0.19 ( $-0.08, 0.46$ )           | .17                               |
| Chair-rise                             | 4                | 185                    | .0078                           | Random | <i>SMD</i> $-0.67$ ( $-1.31, -0.02$ )       | .04                               |
| Gait speed                             |                  |                        |                                 |        |   |                                   |
| Speed                                  | 14               | 798                    | .33                             | Fixed  | <i>WMD</i> 0.07 m/s (0.04, 0.09)            | <.0001                            |
| Timed walk*                            | 4                | 81                     | .96                             | Fixed  | <i>WMD</i> 0.77 s ( $-0.65, 2.2$ )          | .3                                |
| Timed up-and-go*                       | 6                | 494                    | .28                             | Fixed  | <i>WMD</i> $-1.2$ s ( $-2.8, 0.4$ )         | .13                               |
| Physical disability                    |                  |                        |                                 |        |   |                                   |
| Higher score indicates less ability    | 10               | 722                    | .44                             | Fixed  | <i>SMD</i> 0.01 ( $-0.14, 0.16$ )           | .9                                |
| Lower score indicates less disability* | 6                | 559                    | .0081                           | Random | <i>SMD</i> $-0.17$ ( $-0.53, 0.19$ )        | .4                                |
| PF of SF-36                            | 7                | 493                    | .2                              | Fixed  | <i>WMD</i> 0.96 ( $-3.35, 5.26$ )           | .7                                |

Notes: \*Lower score indicates better performance; otherwise, higher score indicates better performance.

CI = confidence interval; *SMD* = standardized mean difference; *WMD* = weighted mean difference; m = meters; s = seconds; m/s = meters per second; PF = physical function domain of the SF-36, range 0–100.

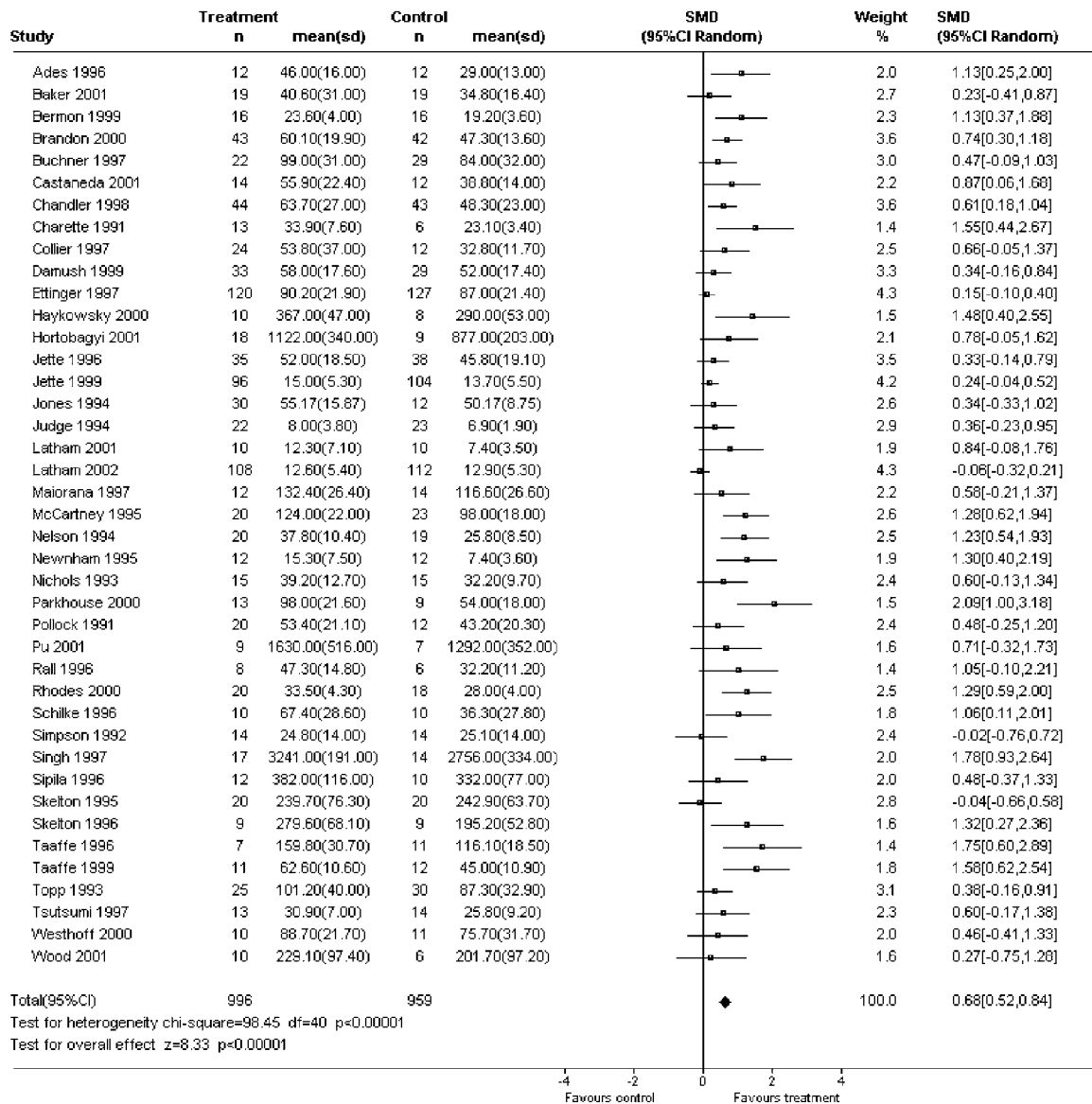


Figure 1. Forest plot of lower-limb strength.

and 2 studies that reported disability used both methods. There was no evidence that PRT had an effect on physical disability, either with the higher score reflecting better measures (*SMD* 0.01; 95% CI -0.14, 0.16) or the lower score reflecting better measures (*SMD* -0.17; 95% CI -0.53, 0.19). When HRQOL and ADL measures were examined separately, there was still no evidence of benefit of PRT. For example, when the PF domain of the SF-36 was pooled, a modest difference of less than 1 point on this 100-point scale was found between the two groups (*WMD* 0.96; 95% CI -3.35, 5.26).

*Effects of PRT—Falls and Other Adverse Events*

Only five studies investigated the effect of PRT on falls, but these data were not reported in a manner that allowed for pooling. Although Donald and colleagues (34) and three trials in the Frailty and Injuries: Cooperative Studies of

Intervention Techniques (FICSIT) preplanned meta-analysis (36,62,63) showed a reduction in falls, the confidence intervals were wide around the risk reduction estimates. Thus, as most of the trials in this overview were small (i.e., *n* < 60), pooling would be unlikely to provide the power necessary to detect a modest effect on falls.

Thirty-two studies did not make any comment about adverse events or side effects associated with PRT. Of the 30 studies that did comment, 14 reported no adverse events and 16 reported some adverse reaction. An additional nine studies did not report adverse events as such, but it is likely that an event occurred, since these studies reported drop-outs from the exercise group secondary to increasing pain or specific injuries (4,21,37,38,48,49,58,60,73). Only 6 of 62 studies provided an a priori definition of an adverse event in the study methods or objectives (20,25,29,35,63,65). Five of these six studies detected adverse events (20,25,35,63,65).

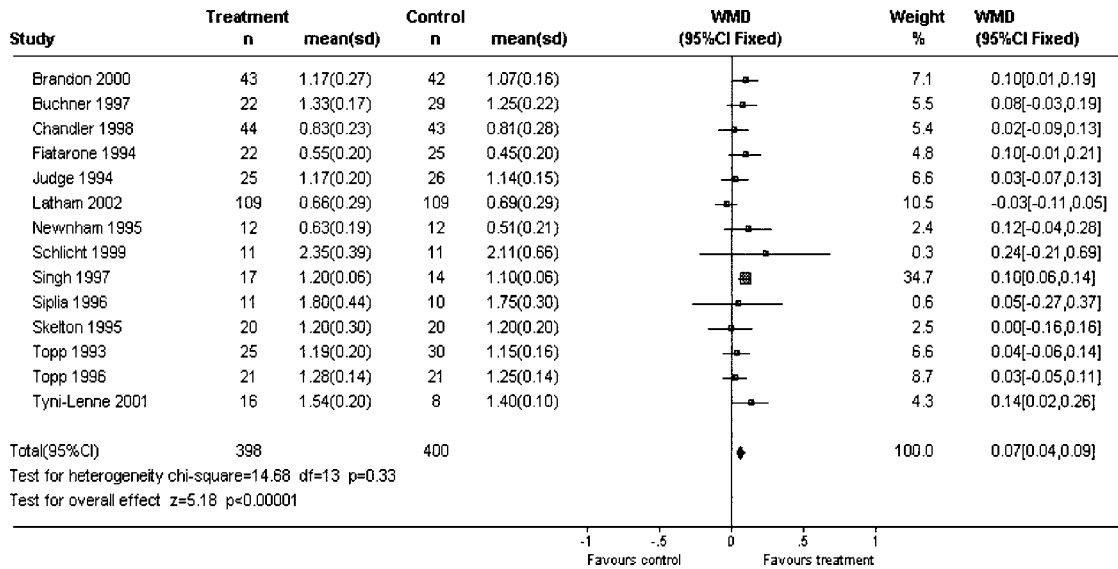


Figure 2. Forest plot of gait speed.

Most adverse events were musculoskeletal problems; there were no reports of cardiac events or death associated with PRT. Three studies provided data about use of health services (29,34,35). Two studies reported decreased rates of hospitalization and/or length of stay, while one reported an increased risk of hospitalization. Six studies provided data on participant deaths (20,25,34–36,41), with 10 deaths reported in the treatment group compared with 17 in the control group (odds ratio [OR] 0.58; 95% CI 0.27, 1.24). In at least two studies (37,64), the death of participants was reported, but these data could not be pooled because the participants' assigned group was not specified.

#### Exploratory Subgroup and Sensitivity Analyses

The large number of participants in this overview allowed sensitivity and subgroup analyses to be undertaken for the strength outcome. To explore the effect of methodological quality, data were stratified by use of factors known to affect a trial's internal validity. Effect estimates were lower in studies that used blinded assessors, concealed allocation, and intention-to-treat analyses (Table 4). The use of attention control groups did not affect the effect estimates. Subgroup analyses were also conducted to explore the impact of differences in the form of exercise program and types of participants. Both high- and low-moderate-intensity PRT had significant effects on strength, but the former method had a larger effect (Table 4). The duration of PRT program (i.e., greater than or less than 12 weeks) appeared to have little effect on outcome (Table 5). However, there was considerable statistical heterogeneity across these data. There was no difference in the treatment effect among participants who were healthy compared with those with specific health problems (Table 5). However, there was a reduced effect in trials that included people with a physical disability or functional limitation, but most of these programs were carried out at a low-to-moderate intensity (Table 5). Since there was considerable statistical hetero-

geneity in these data, caution should be exercised in their interpretation. Sensitivity analyses were conducted to determine whether the removal of one of the largest studies, the Frailty Interventions Trial in Elderly Subjects (FITNESS), would affect outcomes that were assessed in this trial. Excluding the FITNESS trial did not change the significance of strength, gait speed, overall physical disability, or physical disability as assessed by the PF domain of the SF-36. Excluding FITNESS did increase the effect estimates of balance and timed up-and-go measures so that they approached statistical significance, although the effect estimates were still small for both outcomes (balance: *SMD* 0.23, 95% CI 0.06, 0.39, *p* = .07; timed up-and-go: *WMD* -1.62 s, 95% CI -3.24, 0.01, *p* = .05).

#### DISCUSSION

This review identified, graded, and synthesized the literature regarding the effect of a specific form of exercise, PRT, that is widely used in the rehabilitation of older people. Our systematic search strategy allowed the inclusion of trials of participants with a range of health problems, and evaluations of programs with varying intensity and method of delivery of PRT, which increased the external validity and generalizability of the data. We were able to provide an overall assessment of the effects of the intervention on clinically relevant outcomes in older people, based on the current evidence. PRT was found to have a large positive effect on strength, the most proximal measure of impairment, and a small-to-moderate positive effect on other aspects of impairment and functional limitation. However, we were unable to show that these effects of PRT translated into improvements in physical disability, and the data did not allow an adequate assessment of associated risks, although some adverse events, mainly musculoskeletal, were evident in many trials.

A major finding was the poor methodological quality of most of the 62 included studies. As most of the studies did

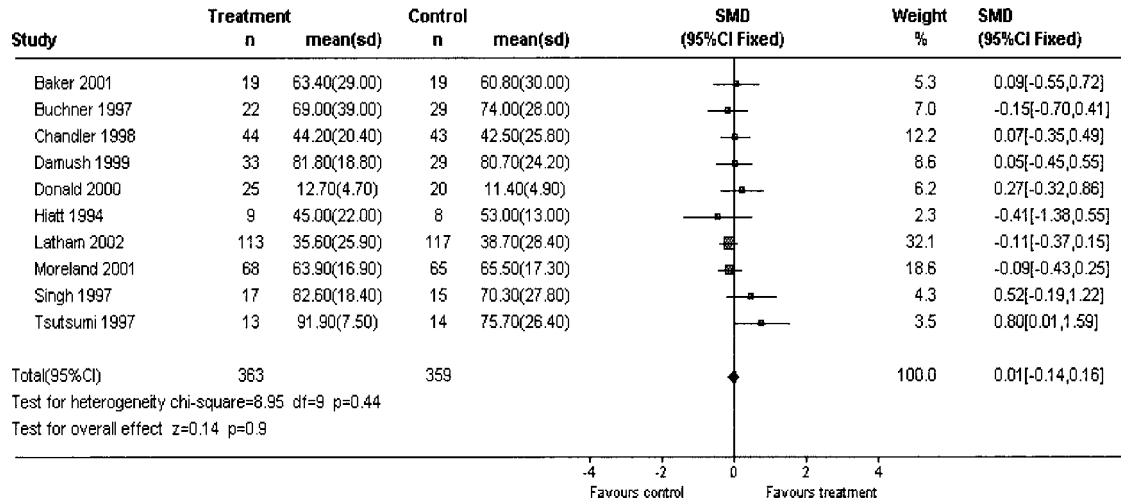


Figure 3. Forest plot of physical disability measures.

not use design features that are known to increase internal validity, such as intention-to-treat analysis, blinded outcome assessors, attention control groups, or concealed randomization, caution is required when drawing conclusions from these data. Our sensitivity analyses suggest that low-quality trials overestimate the effect of PRT; although higher quality trials continued to find a beneficial effect of PRT on strength, the effect size was considerably attenuated.

While PRT had a large positive effect on the strength of older people, there was significant statistical heterogeneity associated with this estimate, which was reduced but not entirely eliminated when the data were pooled separately for trials utilizing different participants, training doses and design features. In exploratory subgroup analyses, it appeared that intensity has the greatest effect, and duration, a much smaller effect, on strength. The small effect of duration could have been influenced by our choice of a cut-off point (12 weeks), since at least one half of strength gain in 1 year occurs during the first 12 weeks of training. The health status of the participants did not have a clear effect on the response to PRT, although it did appear that people with preexisting functional limitations had smaller gains in strength. However, these subgroup analyses must be treated with caution, as the number of participants available in these analyses was small, which decreases the precision of these

estimates. In addition, it is possible that study quality is a confounder for some of these observed differences, as several of the largest and highest quality trials included people with function limitations and/or lower intensity training programs. We chose not to perform meta-regression analyses, as these can be problematic since there are many characteristics that could be investigated but usually only a small number of trials (74). This can lead to data dredging, and false-positive results may occur, which can be misleading for both clinical practice and future research (75).

Adverse events were poorly monitored and reported in most of these trials, making it difficult to assess the risk of injury or other events associated with resistance training. The finding that several studies reported dropouts from the exercise program due to pain or injury, yet failed to report any adverse events, suggests that adverse events might have been under-reported in trials. This hypothesis is also supported by the finding that events were more likely to be reported in studies with a clear definition of adverse events than in those with no definition. Furthermore, the large number of dropouts from PRT also raises the possibility that people left the trials because they experienced adverse effects. However, it is reassuring that there was no evidence of an increased risk of hospitalization or death, and several studies reported decreased use of health

Table 4. Sensitivity Analyses of the Effect of Study Quality on Lower Limb Strength

| Group                       |     | Number of Trials | Number of Participants | Heterogeneity (p Value) | Model  | Effect Size (95% CI)  | Overall Effect on Strength (p Value) |
|-----------------------------|-----|------------------|------------------------|-------------------------|--------|-----------------------|--------------------------------------|
| Blinded assessors           | Yes | 10               | 1010                   | .098                    | Random | SMD 0.29 (0.12, 0.47) | .001                                 |
|                             | No  | 31               | 945                    | .01                     | Random | SMD 0.83 (0.64, 1.01) | <.0001                               |
| Concealed randomization     | Yes | 9                | 570                    | .031                    | Random | SMD 0.38 (0.07, 0.70) | .02                                  |
|                             | No  | 32               | 1385                   | .0003                   | Random | SMD 0.78 (0.60, 0.96) | <.0001                               |
| Intention-to-treat analysis | Yes | 7                | 656                    | .025                    | Random | SMD 0.33 (0.05, 0.61) | .02                                  |
|                             | No  | 34               | 1299                   | .0012                   | Random | SMD 0.76 (0.59, 0.93) | <.0001                               |
| Attention control           | Yes | 12               | 830                    | <.0001                  | Random | SMD 0.63 (0.31, 0.94) | <.0001                               |
|                             | No  | 29               | 1125                   | .013                    | Random | SMD 0.70 (0.52, 0.87) | <.0001                               |

Note: CI = confidence interval; SMD = standardized mean difference.



Table 5. Subgroup Analysis of the Effect of Exercise Dose and Participant Characteristics on Lower Limb Strength

| Group                             | Number of Trials | Number of Participants | Heterogeneity (p Value) | Model  | Effect Size (95% CI)  | Overall Effect on Strength (p Value) |
|-----------------------------------|------------------|------------------------|-------------------------|--------|-----------------------|--------------------------------------|
| Exercise dose                     |                  |                        |                         |        |                       |                                      |
| High intensity                    | 32               | 1357                   | <.0001                  | Random | SMD 0.81 (0.60, 1.01) | <.0001                               |
| Low intensity                     | 9                | 598                    | .54                     | Fixed  | SMD 0.34 (0.18, 0.51) | <.0001                               |
| Short duration ( $\leq 12$ weeks) | 25               | 1007                   | .0015                   | Random | SMD 0.62 (0.42, 0.82) | <.0001                               |
| Longer duration ( $< 12$ weeks)   | 16               | 948                    | <.0001                  | Random | SMD 0.77 (0.50, 1.05) | <.0001                               |
| Participant characteristics       |                  |                        |                         |        |                       |                                      |
| Specific health problem           |                  |                        |                         |        |                       |                                      |
| Yes                               | 15               | 1016                   | .029                    | Random | SMD 0.69 (0.51, 0.86) | <.0001                               |
| No                                | 26               | 939                    | <.0001                  | Random | SMD 0.69 (0.51, 0.86) | <.0001                               |
| Functional limitations            |                  |                        |                         |        |                       |                                      |
| Yes                               | 9                | 871                    | .017                    | Random | SMD 0.36 (0.11, 0.60) | .004                                 |
| No                                | 32               | 1084                   | .0064                   | Random | SMD 0.76 (0.59, 0.94) | <.0001                               |

Note: CI = confidence interval; SMD = standardized mean difference.

care services in the PRT group. In addition, there were no reports of serious adverse events (i.e., death or illness resulting in hospitalization) associated with PRT. Unfortunately, the sparse data did not allow an adequate assessment of the effect of PRT on fall risk.

To address these issues, it is imperative that future trials of PRT in older people utilize rigorous designs that minimize bias, recruit an adequate number of participants, assess substantive outcomes such as disability, and carefully monitor adverse events. Well-designed trials are also required to determine the most appropriate dose to use (i.e., high intensity compared with low intensity) with different participants, particularly people with preexisting functional limitations and disability, and in different settings (i.e., home based versus gym based). New data, obtained from newly identified trials or provided by authors of currently included trials, will be incorporated in updates of the full review of this topic, which is part of the Cochrane Collaboration.

A systematic and quantitative synthesis of the effectiveness of PRT has shown that it increases strength and has a positive effect on several important functional limitations in older people. However, based on current data, there is no evidence that PRT alone has an effect on physical disability. It is possible that, to impact at this higher level of functioning, PRT needs to be combined with other forms of exercise (e.g., balance training) and that more consideration needs to be given to other factors that contribute to disability such as self-efficacy, motivation, or barriers to participation. Because of uncertainty about the risk of adverse effects associated with PRT, some caution appears warranted in utilizing this intervention in widespread clinical practice, particularly in unsupervised high-intensity programs for people who could potentially be at higher risk of injury. Thus, clinicians should monitor for adverse effects in older people undertaking PRT, particularly in older people who are frail or have been ill recently. However, when assessing the risks and benefits of PRT, it is important to note that inactivity also has serious negative consequences for older people. In summary, PRT shows promise in improving some important functional limi-

tations in older people, but current evidence does not indicate that these changes are sufficient to improve older people's level of physical disability.

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