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Research

Resistance training leads to large improvements in strength and moderate improvements in physical function in adults who are overweight or obese: a systematic review

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KEY WORDS

Obesity
Resistance training
Physical functional performance
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Muscle strength
Muscle power

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ABSTRACT

Questions: What are the effects of resistance training on muscle strength, physical function and muscle power in adults who are overweight or obese? Which factors moderate the effects? **Design**: Systematic review of randomised controlled trials, with random effects meta-analyses and meta-regressions. **Participants**: Adults who are overweight or obese. **Intervention**: Resistance training lasting $\geq$ 4 weeks. **Outcome measures**: Muscle strength, muscle power and physical function. **Results**: Thirty trials with 1,416 participants met the eligibility criteria. Pooled analyses indicated that resistance training has a large beneficial effect on muscle strength (SMD 1.39, 95% CI 1.05 to 1.73, I^2 = 85%) and a moderate effect on physical function (SMD 0.67, 95% CI 0.25 to 1.08, I^2 = 71%) in adults who are overweight or obese. However, the effect of resistance training on muscle power was unclear (SMD 0.42, 95% CI −3.3 to 4.2, I^2 = 46%). The effect of resistance training on strength was greatest for the upper body (versus lower/whole body: β = 0.35, 95% CI 0.05 to 0.66) and in dynamic strength tests (versus isometric/isokinetic: β = 1.20, 95% CI 0.60 to 1.81), although trials judged to have good methodological quality reported statistically smaller effects (versus poor/fair quality: β = −1.21, 95% CI −2.35 to −0.07). Concomitant calorie restriction did not modify strength gains but reduced the effect of resistance training on physical function (β = −0.79, 95% CI −1.41 to −0.17). Small study effects were evident for strength outcomes (β = 5.9, $p < 0.001$). **Conclusions**: Resistance training has a large positive effect on muscle strength and a moderate effect on physical function in adults who are overweight or obese. However, the effect of resistance training on muscle power is uncertain. In addition, concomitant calorie restriction may compromise the functional adaptations to resistance training. **Registration**: PROSPERO CRD42019146394 **[Orange ST, Madden LA, Vince RV (2020) Resistance training leads to large improvements in strength and moderate improvements in physical function in adults who are overweight or obese: a systematic review. *Journal of Physiotherapy* 66:214–224]**

Introduction

Obesity causes a decline in skeletal muscle contractile function.[1] Adults who are overweight or obese display a substantial reduction in relative muscle strength and power compared with their lean counterparts.[2] Preclinical models also show that intramuscular fat decreases the intrinsic capacity of isolated muscle fibres to produce force.[3,4] These physiological impairments lead to reduced physical function and the development of physical disabilities, which ultimately decrease motivation to exercise and thus contribute to a perpetuating cycle of inactivity and weight gain.[5] Therefore, improving muscle strength, power and physical function are key objectives in the management of obesity.

Resistance training provides a potent stimulus to modify muscle performance and physical function. The American College of Sports Medicine and World Health Organization recommend that adults with obesity perform strength-promoting exercise on $\geq$ 2 days per week.[6,7] However, whilst several meta-analyses have summarised the effects of resistance training across apparently healthy populations,[8–10] the evidence is yet to be quantitatively synthesised with respect to obese adults. This is important because excess body fat appears to reduce the magnitude of adaptation in response to resistance training.[11–13] A quantitative review of randomised controlled trials is required to support the potential inclusion of resistance training in the management of obesity.

Therefore, the research questions for this systematic review were:

1. What are the effects of resistance training on muscle strength, physical function and muscle power in adults who are overweight or obese?
2. Which factors moderate the effects?

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Box 1. Summary of search strategy used in PubMed database.

[All fields] 'resistance training' OR 'strength training' OR 'resistance exercise' OR 'weight training'

AND

[All fields] overweight OR obes*

AND

[All fields] strength OR power OR function*

Box 2. Inclusion criteria.

Design
- Randomised trial
- Published in a peer-reviewed journal
- Full text available in English

Participants
- Age $\geq$ 18 years
- Classified as overweight or obese[15]

Intervention
- Resistance training intervention lasting $\geq$ 4 weeks

Outcome measures
- Muscle strength
- Muscle power
- Physical function

Comparison
- Resistance training versus no structured exercise intervention
- Resistance training plus dietary intervention (eg, calorie restriction) versus dietary intervention alone

Methods

This review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[14]

Identification and selection of the trials

An electronic search of PubMed, Scopus, SportDiscus, Web of Science, and CINAHL databases was conducted from inception of indexing to 23 September 2019. Search terms included 'resistance training', 'strength training', 'resistance exercise', 'weight training', 'overweight', 'obes*', 'strength', 'power' and 'function*'. Standard Boolean operators (AND, OR) were used to link the search terms, as displayed in Box 1. The reference lists of included studies and relevant review articles were also manually screened.

Inclusion criteria are presented in Box 2. Studies were excluded if: the resistance training intervention was combined with other types of exercise (eg, aerobic) that were not just part of the warm-up; the participants were recruited on the basis of any chronic disease other than weight status (eg, cancer, metabolic syndrome and sarcopenia) or medical procedure (eg, bariatric surgery); the measures of physical function were subjective (eg, questionnaires); or the results were uninterpretable due to insufficient data being available (eg, not reporting baseline and post-intervention or change score data for exercise and control groups). Resistance training was defined as a sequence of dynamic strength exercises that utilised concentric and eccentric muscular contractions. The type of resistance could include elastic bands/tubing, free weights, weight-training machines or the participant's body weight. No restrictions were placed on the level of supervision or location of training (eg, gym or home). The control condition could consist of: instruction not to deviate from habitual physical activity levels, encouragement to follow general physical activity recommendations only, provision of a sham intervention (eg, stretching) or provision of a dietary-only intervention (eg, calorie restriction).

Once all literature searches were complete, studies were compiled into a single list in a spreadsheet[a]. One author (STO) removed duplicates and screened the titles and abstracts to identify potentially relevant trials. Full-text was then obtained for all studies that appeared to meet the inclusion criteria or where there was any uncertainty. Subsequently, two authors (STO, LAM) independently examined each full-text manuscript to assess for eligibility. Neither of the review authors was blind to the journal titles or study authors. Any disagreements were resolved through discussion or consultation with the third author (RVV). Study authors were contacted if a full-text manuscript could not be retrieved or to clarify aspects of the study in relation to the inclusion criteria.

Assessment of characteristics of the trials

Quality

The methodological quality of each included trial was assessed with the 11-item Physiotherapy Evidence Database (PEDro) Scale.[16] The items relate to eligibility criteria specification, random allocation, allocation concealment, baseline comparability, blinding of participants, blinding of intervention providers, blinding of outcome assessors, attrition < 15%, intention-to-treat analysis, reporting of between-group comparisons, and reporting of point measures with measures of variability. The last four items relate to 'at least one key outcome'.[16] For the purposes of this review, a 'key outcome' was defined as a measure of strength, power or physical function. Each trial was given a total PEDro score, ranging from 0 to 10 (the first item was not included in the total score). Scores of 0 to 3, 4 to 6 and 7 to 10 were considered poor, fair and good quality, respectively.[17,18] Judgements were made independently by two authors (STO, LAM), with disagreements resolved firstly by discussion and then by consulting the third author (RVV).

Participants

To be included, trials had to involve adult participants of either gender who were classified as overweight or obese based on body mass index ($\geq$ 25 kg/m^2), body fat percentage ($\geq$ 25% for men and $\geq$ 30% for women) or waist circumference ($\geq$ 102 cm for men and $\geq$ 88 cm for women).[15] The number of participants, sex, age and weight-based eligibility criteria were recorded to describe the participants.

Interventions

The number of repetitions, sets, sessions per week and total duration of the intervention period were recorded to describe the interventions. We also recorded whether calorie restriction was imposed in the experimental and control groups.

Outcome measures

All outcomes were continuous variables and determined as the change from baseline to post-intervention. Strength outcomes included upper-body and lower-body dynamic (eg, one repetition maximum, 1RM) and isokinetic/isometric tests. If studies reported multiple strength outcomes within the same subgroup, only one representative variable was used for further analysis. The highest priority was given to multi-jointed strength tests that recruited major muscle groups (eg, leg press over knee extension). Hand grip strength was not included as an outcome because it is well established that grip strength does not change appreciably with resistance training.[19] Measures of physical function included tasks that evaluated gait speed (eg, 4-m walk test), waking capacity (eg, 6-minute walk test, 6MWT), sit-to-stand (STS) performance, basic mobility (eg, Timed Up and Go test or stair climbing) and overall functional ability (eg, Short Physical Performance Battery or Physical Performance Test). Measures of power included dynamic (eg, leg press) and isokinetic tests (eg, isokinetic knee extension).

Data extraction

In addition to the details of the participants, interventions and outcome measures discussed above, data items extracted from each of the eligible studies included the baseline, post-intervention and/or change score data for each key outcome measure. If individual studies involved multiple resistance training groups, we combined these treatment arms into a single group[20] unless the resistance training groups differed with respect to calorie restriction. In this case, they were reported separately because we prospectively planned to investigate whether including calorie restriction alongside resistance training was a source of heterogeneity in the treatment effect. Where a study was reported in multiple manuscripts, data extraction was performed separately and study information was collated afterwards. All data were extracted independently by two authors (STO, LAM) and tabulated in a spreadsheet[a] that was custom-designed for this review. Review authors cross-checked coding sheets and resolved any discrepancies with discussion. Study authors were contacted to obtain missing data wherever necessary.

Data analyses

To quantify the magnitude of effects, standardised mean differences (SMDs) between intervention and control groups were calculated as: (mean change intervention group − mean change control group)/pooled SD of change scores. Hedges' *g* correction was applied to adjust for population bias. Improvements from baseline within individual studies were presented as positive SMDs and reductions from baseline reported as negative SMDs. Qualitative descriptors used to interpret the strength of the SMDs were based on Cohen's[21] criteria: trivial (< 0.2), small (0.2 to 0.49), moderate (0.5 to 0.79) and large (≥ 0.8).

If the mean change was not reported, it was calculated as the difference between the baseline and post-intervention scores. In the case that the SD of the change score (SD_{diff}) was not reported, it was estimated using the change score 95% CI, standard error or with the baseline SD ($SD_{baseline}$) and post-intervention SD (SD_{post}) in addition to the within-groups bivariate correlation coefficient (r)[22]:

$$SD_{diff} = \sqrt{SD^2_{baseline} + SD^2_{post} - (2\times r \times SD_{baseline} \times SD_{post})}$$

Corresponding authors were contacted to retrieve the SD_{diff} in all necessary cases. If the authors for a given study could not be contacted, the guidelines by Rosenthal[23] were followed to assume a conservative pre-post correlation of 0.7. Sensitivity analyses were performed with $r = 0.5$ and $r = 0.9$ to determine whether the results were robust to the use of imputed correlations. In the case that a study reported standard errors for group means rather than SDs, the SD was calculated as the standard error multiplied by $\sqrt{N}$.[22]

When two or more studies reported on the same outcome, effect estimates and their 95% CIs were pooled using a random-effects model with a three-level structure. SMDs were nested within intervention groups to account for correlated effects within studies.[24] The model was fitted with the maximum likelihood estimation and studies were weighted according to the inverse of the sampling variance. CIs were calculated using the Hartung-Knapp-Sidik-Jonkman method. A random-effects model was chosen to account for variability in participant characteristics (eg, age) and interventions received (eg, resistance training load, volume and duration) across trials included in this review.

The magnitude of heterogeneity not attributable to sampling error was evaluated with I^2. Thresholds of heterogeneity were set as $I^2 = 25\%$ (low), $I^2 = 50\%$ (moderate) and $I^2 = 75\%$ (high).[25] The *p*-value was also reported from the Chi-squared test. Small study effects were explored with Egger's regression test with associated funnel plots. Furthermore, given that extreme effect estimates can distort conclusions of meta-analyses, it is recommended that effect sizes should be examined for potential outliers and influential cases.[26] A study was considered an outlier if the 95% CI of the effect size did not overlap with the 95% CI of the overall effect. Influential cases were identified by graphically inspecting Cook's distance, studentised difference in fits (DFFITS), and standardised residuals.[26] If a study was considered an outlier and had an extreme influence on the model, it was removed from analysis. In this case, a sensitivity analysis was performed with the study included to determine whether the removal influenced the model parameters.

Subgroup analyses was performed on strength outcomes with muscle group (upper-body versus lower-body versus composite measures of total-body strength) as the subgroup. Measures of physical function were also subdivided into two distinct categories: activities of daily living (eg, stair climbing, Timed Up and Go, repeated STS tests and functional testing batteries), and gait speed (eg, 4-m walk test and 6MWT). In an effort to further explore the heterogeneity in SMDs, separate meta-regressions were performed with age, calorie restriction and methodological quality as covariates. Additional meta-regressions involved specificity of the strength test (ie, dynamic versus isometric/isokinetic) and muscle group for strength outcomes, and type of functional test (ie, activities of daily living versus gait speed) for function outcomes. Age was entered as a continuous variable whereas all other predictors were categorical variables. The variables were meta-regressed individually in multilevel random-effects models using the maximum likelihood method to estimate model parameters. Neither subgroup analyses nor meta-regressions were performed on changes in power because insufficient data were available.

All statistical analyses were conducted using package metaphor in R software[b]. Statistical significance was set at $p < 0.05$. Data are presented as SMD (95% CI). Statistical code and datasets are available online.[27]

Results

Flow of trials through the review

The primary search yielded 3,398 papers (Figure 1), of which 179 full texts were assessed for eligibility, and 39 manuscripts reporting 30 randomised trials[28–66] met the eligibility criteria (Table 1). No additional studies were included from scanning reference lists or other sources.

Characteristics of the included trials

Quality

Of the 30 trials included in the review, 11 were considered of poor methodological quality (37%), 16 were considered fair quality (53%) and three were considered good quality (10%). The median score was 4. Quality ratings for each study are presented in Table 2.

Participants

The 30 included trials involved 1,416 participants, with sample sizes of the individual trials ranging from 17 to 163 (median 38). Participant characteristics are detailed in Table 1.

Intervention

The resistance training interventions lasted between 8 weeks and 2 years (median 12 weeks) and involved two to three sessions per week: 1 to 4 sets of 2 to 22 repetitions of 4 to 13 different resistance exercises (except for one treatment group in Rustaden et al,[53] which performed 50 to 100 repetitions per set). Most interventions exclusively involved supervised interventions in gym-based settings, except: one treatment group in Rustaden et al[53] trained unsupervised in a health and fitness centre for the entire 12-week intervention; the treatment group in Warren et al[62] trained unsupervised after the initial 16 weeks of supervised training; and the resistance training group in Herring et al[38] performed one training session per week unsupervised at home in addition to two supervised gym-based sessions. All interventions included the use of free weights and/or resistance machines, apart from one study that used elastic bands[37]

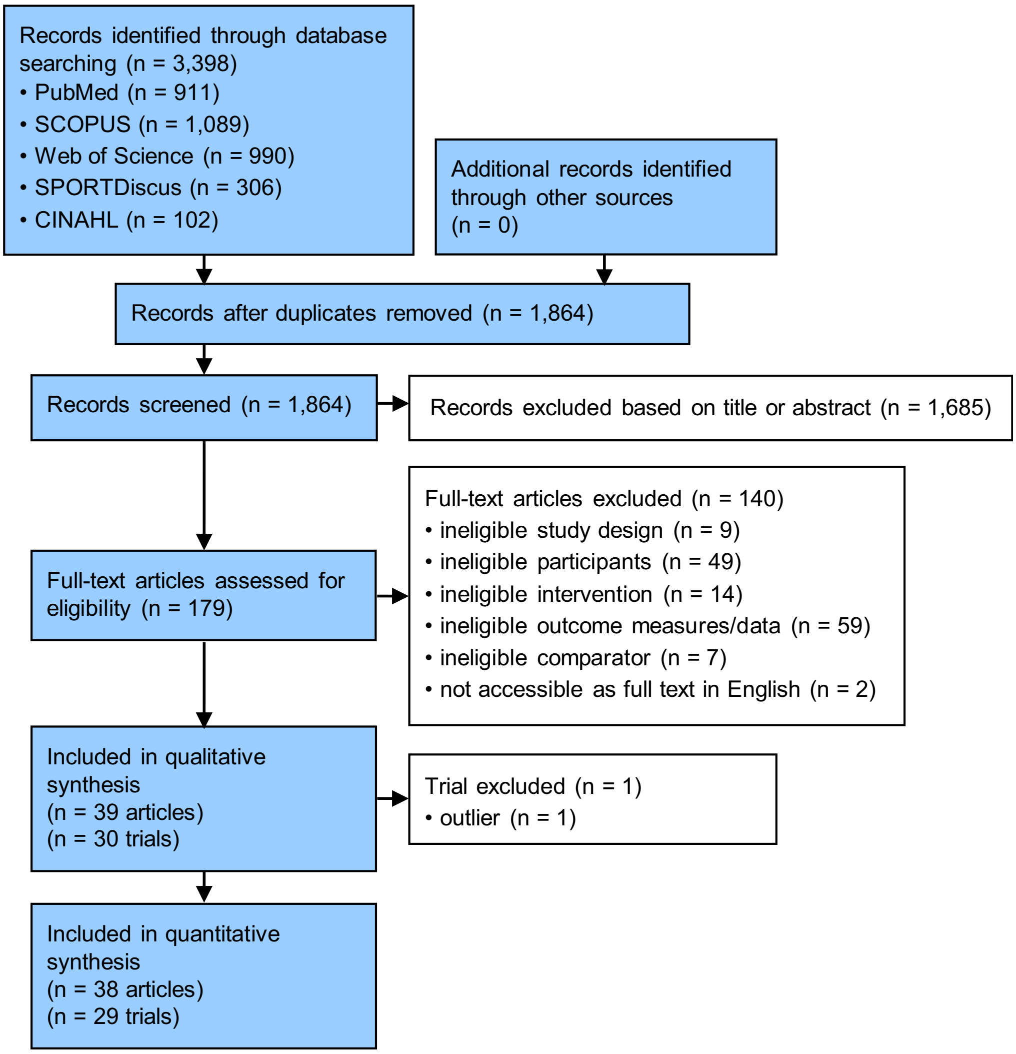

Figure 1. PRISMA flow diagram of systematic search and included studies.

and another study that used a combination of free weights, medicine balls and elastic bands.[57]

Outcome measures

The outcome measures in each study in the categories of strength, power and physical function are detailed in Table 1.

Heterogeneity

Following an examination of outlier and influential case diagnostics, one study[37] was removed before conducting the meta-analyses on strength and physical function outcomes (see Figure 2 on the eAddenda). There was evidence of large heterogeneity for strength outcomes (I^2 = 85%, $p < 0.001$) and moderate heterogeneity for measures of physical function (I^2 = 71%, $p < 0.001$) and power (I^2 = 46%, p = 0.047). Funnel plot analysis of strength outcomes showed visible asymmetry and Egger's regression test was statistically significant (β = 5.9, $p < 0.001$). In contrast, the funnel plot of physical function outcomes showed reasonable symmetry and Egger's test showed no evidence of small study effects (β = 2.4, p = 0.39; see Figure 3 on the eAddenda). There were insufficient studies to inspect small study effects for power outcomes (n = 2).

Effect of intervention

Strength

The overall meta-analysis of the effect of resistance training on strength outcomes comprised 42 SMDs from 26 trials (Figure 4). Overall, resistance training significantly improved muscle strength compared with controls (SMD 1.39, 95% CI 1.05 to 1.73). Subgroup analyses showed that resistance training markedly improved lower-body strength (SMD 1.30, 95% CI 0.90 to 1.70) and upper-body strength (SMD 1.77, 95% CI 1.29 to 2.25). In contrast, the interval estimate for the effect of resistance training on whole-body strength showed a high level of uncertainty (SMD 0.96, 95% CI −0.30 to 2.22).

Physical function

The overall meta-analysis of the effect of resistance training on physical function comprised 23 SMDs from seven trials (Figure 5). Resistance training significantly improved physical function (SMD 0.67, 95% CI 0.25 to 1.08). Subgroup analyses demonstrated that resistance training significantly increased the ability to perform activities of daily living (SMD 0.59, 95% CI 0.04 to 1.13) and gait speed (SMD 0.54, 95% CI 0.08 to 1.00).

Power

There were two SMDs from two trials that reported the effects of resistance training on outcomes of muscle power.[28,44] Pooling these two SMDs showed no difference between resistance training and control groups (SMD 0.42, 95% CI −3.3 to 4.2).

Sensitivity analyses

Sensitivity analyses showed that removing an outlying study[37] did not sufficiently influence the overall results from the meta-analyses on strength (SMD 1.52, 95% CI 1.2 to 1.9, I^2 = 91%) or physical function (SMD 1.26, 95% CI 0.10 to 2.4, I^2 = 96%) to substantially alter the

Table 1
Description of included studies

Study	Participants[a]	Intervention	Calorie restriction	Outcomes included in review		
				Strength	Function	Power
Avila 2010[28]	n = Exp: 15, Con: 12 Sex = M and F Age *(yr)* = Exp: 66 (4), Con: 67 (5) Elig: 25 to 39.9 kg/m^2	8 to 12 reps × 4 sets × 3/wk × 10 wk Load = NR	Exp: Yes Con: Yes	• LP 1RM	• SPPB • 4 m GS • 5 × STS • 400 m GS	• LP PP
Ballor 1988[29]	n = Exp_1: 10, Exp_2: 12, Con_1: 8, Con_2: 10 Sex = F Age *(yr)* = Exp_1: 33 (6), Exp_2: 33 (4), Con_1: 31 (4), Con_2: 35 (5) Elig: > 30% body fat	10 reps × 3 sets × 3/wk × 8 wk Load = 10RM	Exp_1: No Exp_2: Yes Con_1: No Con_2: Yes	• BP 1RM		
Bouchard 2009[30]	n = Exp_1: 11, Exp_2: 12, Con_1: 12, Con_2: 11 Sex = F Age *(yr)* = Exp_1: 63 (4), Exp_2: 64 (5), Con_1: 63 (3), Con_2: 61 (5) Elig: > 35% body fat	8 reps × 3 sets × 3/wk × 12 wk Load = 80% 1RM	Exp_1: No Exp_2: Yes Con_1: No Con_2: Yes	• ISO KE	• 30 s STS • 6MWT • 50 ft GS • GPCS • SC	
Davidson 2009[33]	n = Exp: 28, Con: 8 Sex = M Age *(yr)* = Exp: 22 (2), Con: 22 (1) Elig: ≥ 27 kg/m^2	6 to 15 reps × 2 to 3 sets × 3/wk × 12 wk Load = 6RM to 15RM	Exp: No Con: No	• LP 1RM • BP 1RM		
Croymans 2014[31] and Roberts 2013[32]	n = Exp: 36, Con: 28 Sex = M and F Age *(yr)* = Exp: 68 (5), Con: 67 (4) Elig: waist ≥ 102 cm (M) or ≥ 88 cm (F)	NR reps × 1 sets × 3/wk × 26 wk Load = failure	Exp: No Con: No		• 30 s STS • TUG	
Donges 2013[34]	n = Exp: 13, Con: 8 Sex = M Age *(yr)* = Exp: 52 (8), Con: 50 (7) Elig: ≥ 25 kg/m^2	8 to 10 reps × 3 to 4 sets × 3/wk × 12 wk Load = 75 to 80% 1RM	Exp: No Con: No	• LP 5RM • CP 5RM		
Fernandez-Real 2009[35]	n = Exp: 11, Con: 8 Sex = F Age *(yr)* = Exp: 48 (7), Con: 52 (7) Elig: 30 to 40 kg/m^2	NR reps × NR sets × 2/wk × 16 wk Load = NR	Exp: Yes Con: Yes	• LP 1RM • CP 1RM		
Figueroa 2013[36]	n = Exp: 14, Con: 13 Sex = F Age *(yr)* = Exp: 54 (4), Con: 54 (4) Elig: ≥ 25 kg/m^2	18 to 22 reps × 3 to 4 sets × 3/wk × 12 wk Load = 20RM	Exp: Yes Con: Yes	• LP 8RM		
Fritz 2018[37]	n = Exp: 43, Con: 20 Sex = F Age *(yr)* = Exp: 70 (1), Con: 67 (1) Elig: ≥ 25 kg/m^2	10 reps × 3 to 4 sets × 2/wk × 8 wk Load = 7 to 9 RPE	Exp: No Con: No	• ISO UR • ISO SQ	• 30 s STS • TUG • 6MWT	
Herring 2014[38]	n = Exp: 10, Con: 7 Sex = M and F Age *(yr)* = 24 to 68 Elig: ≥ 40 kg/m^2, or ≥ 35 kg/m^2 with comorbidities	NR reps × NR sets × 3/wk × 12 wk Load = 60% 1RM	Exp: No[b] Con: No[b]		• ISWT	
Hunter 2008[39,40]	n = Exp: 37, Con: 26 Sex = F Age *(yr)* = Exp: 35 (6), Con: 35 (5) Elig: > 27 and < 30 kg/m^2	10 reps × 1 to 2 sets × 3/wk × > 4 wk (mean 25) Load = 65 to 80% 1RM	Exp: Yes Con: Yes	• ISO KE • ISO EF		
Hunter 2012[41]	n = Exp: 26, Con: 28 Sex = F Age *(yr)* = Exp: 34 (7), Con: 36 (5) Elig: 27 to 30 kg/m^2	10 reps × 1 to 2 sets × 2 to 3/wk × > 52 wk Load = 65 to 80% 1RM	Exp: Yes Con: Yes	• ISO KE		
Kirk 2007[42]	n = Exp: 11, Con: 8 Sex = M Age *(yr)* = Exp: 21 (2), Con: 20 (3) Elig: 25 to 29.9 kg/m^2	3 to 6 reps × 1 sets × 3/wk × 24 wk Load = 3RM to 6RM	Exp: No Con: No	• LP 1RM • CP 1RM		
Loria-Kohen 2013[43]	n = Exp: 19, Con: 18 Sex = M and F Age *(yr)* = Exp: 36 (9), Con: 37 (9) Elig: ≥ 25 and < 30 kg/m^2	15 reps × 2 to 3 sets × 3/wk × 22 wk Load = 50 to 60% 15RM	Exp: Yes Con: Yes	• DSI		
Marsh 2013[44]	n = Exp: 42, Con: 39 Sex = M and F Age *(yr)* = Exp: 70 (4), Con: 70 (4) Elig: ≥ 30 kg/m^2, or ≥ 25 kg/m^2 with comorbidities	8 to 10 reps × 2 to 3 sets × 3/wk × 16 wk Load = 40 to 70% 1RM	Exp: Yes Con: Yes	• ISO KE		• LP PP
Messier 2010[45] and Normandin 2015[46]	n = Exp: 35, Con: 52 Sex = F Age *(yr)* = Exp: 58 (5), Con: 57 (5) Elig: ≥ 27 kg/m^2	8 to 15 reps × 2 to 4 sets × 3/wk × 26 wk Load = 65 to 80% 1RM	Exp: Yes Con: Yes	• LP 1RM • CP 1RM		

Table 1 (*Continued*)

Study	Participants[a]	Intervention	Calorie restriction	Outcomes included in review		
				Strength	Function	Power
Romero Moraleda 2013[47]	n = Exp: 24, Con: 22 Sex = M and F Age *(yr)* = Exp: 36 (9), Con: 37 (9) Elig: 30 to 34.9 kg/m^2	15 reps × 2 to 3 sets × 3/wk × 22 wk Load = 50 to 60% 15RM	Exp: Yes Con: Yes	• DSI		
Nikseresht 2014, 2016, 2018[48–51]	n = Exp: 12, Con: 10 Sex = M Age *(yr)* = Exp: 40 (5), Con: 39 (4) Elig: > 25% body fat	2 to 20 reps × 1 to 4 sets × 3/wk × 12 wk Load = 40 to 95% 1RM	Exp: No Con: No	• KE 1RM • BP 1RM		
Olson 2007[52]	n = Exp: 15, Con: 15 Sex = F Age *(yr)* = Exp: 38 (1), Con: 38 (2) Elig: > 25 kg/m^2	8 to 10 reps × 3 sets × 2/wk × 52 wk Load = NR	Exp: No Con: No	• LP 1RM • BP 1RM		
Rustaden 2017[53]	n = Exp: 69, Con: 23 Sex = F Age *(yr)* = Exp: 40 (10), Con: 40 (10) Elig: ≥ 25 kg/m^2	Exp_1: 50 to 100 reps × 9 sets × 3/wk × 12 wk Exp_2: 3 to 15 reps × 2 to 4 sets × 3/wk × 12 wk Exp_3: 3 to 15 reps × 2 to 4 sets × 3/wk × 12 wk Exp_1 load = 1 to 6 kg Exp_2 load = 3RM to 15RM Exp_3 load = 3RM to 15RM	Exp: No Con: No	• SQ 1RM • BP 1RM		
Saremi 2011[54]	n = Exp: 10, Con: 9 Sex = F Age *(yr)* = 23 (3) Elig: ≥ 25 kg/m^2	8 to 20 reps × 2 to 3 sets × 3/wk × 12 wk Load = 40 to 85% 1RM	Exp: No Con: No	• LP 1RM • BP 1RM		
Sarsan 2006[55]	n = Exp: 20, Con: 20 Sex = F Age *(yr)* = Exp: 43 (10), Con: 44 (6) Elig: ≥ 30 kg/m^2	10 reps × 1 to 3 sets × 3/wk × 12 wk Load = 40 to 80% 1RM	Exp: No Con: No	• KE 1RM • CP 1RM	• 6MWT	
Tomeleri 2016[56]	n = Exp: 19, Con: 19 Sex = F Age *(yr)* = Exp: 67 (3), Con: 70 (5) Elig: ≥ 32% body fat	10 to 15 reps × 3 sets × 3/wk × 8 wk Load = 10RM to 15RM	Exp: No Con: No	• KE 1RM • CP 1RM		
Verreijen 2017[57]	n = Exp: 57, Con: 43 Sex = M and F Age *(yr)* = Exp: 62 (6), Con: 63 (5) Elig: ≥ 28 kg/m^2, or > 25 kg/m^2 if waist > 102 cm (M) or > 88 cm (F)	50 to 75 s × 2 to 3 sets × 3/wk × 10 wk Load = NR	Exp: Yes Con: Yes		• 400 m GS • 4 m GS • 5 × STS	
Villareal 2017[58] and Colleluori 2019[59]	n = Exp: 40, Con: 40 Sex = M and F Age *(yr)* = Exp: 70 (5), Con: 70 (5) Elig: ≥ 30 kg/m^2	8 to 12 reps × 1 to 3 sets × 3/wk × 26 wk Load = 65 to 85% 1RM	Exp: Yes Con: No[b]	• Total 1RM	• PPT • 25 ft GS	
Vincent 2006[60]	n = Exp: 19, Con: 10 Sex = M and F Age *(yr)* = Exp: 67 (1), Con: 71 (2) Elig: ≥ 25 kg/m^2	8 to 13 reps × 1 sets × 3/wk × 24 wk Load = 50 to 80% 1RM	Exp: No Con: No	• Total 1RM		
Warren 2008, 2009[62,66] and Schmitz 2007[61]	n = Exp: 81, Con: 82 Sex = F Age *(yr)* = Exp: 36 (5), Con: 30 (3) Elig: 25 to 35 kg/m^2	8 to 10 reps × 2 to 3 sets × 2/wk × 104 wk Load = 10RM	Exp: No Con: No	• LP 1RM • BP 1RM		
Wong 2019[63]	n = Exp: 10, Con: 10 Sex = F Age *(yr)* = Exp: 54 (3), Con: 55 (3) Elig: 30 to 40 kg/m^2	18 to 22 reps × 2 to 3 sets × 3/wk × 12 wk Load = 20RM	Exp: No Con: No	• LP 8RM		
Wooten 2011[64]	n = Exp: 7, Con: 11 Sex = F Age *(yr)* = Exp: 64 (1), Con: 67 (1) Elig: 30 to 40 kg/m^2	8 reps × 3 sets × 3/wk × 12 wk Load = 8RM	Exp: No Con: No	• LP 8RM • CP 8RM		
Yoon 2018[65]	n = Exp: 10, Con: 10 Sex = F Age *(yr)* = Exp: 52 (2), Con: 53 (3) Elig: ≥ 30% body fat	8 to 12 reps × 3 sets × 3/wk × 12 wk Load = 60% 1RM	Exp: No Con: No	• ISOK KE		

BP = bench press, CP = chest press, Con = control group, DSI = dynamometric strength index, EF = elbow flexion, Elig = overweight/obesity criteria for study eligibility, Exp = experimental group, F = female, GPCS = global physical capacity score, GS = gait speed, ISO = isometric, ISOK = isokinetic, ISWT = incremental shuttle walk test, KE = knee extension, LP = leg press, M = male, NR = not reported, PP = peak power, PPT = Physical Performance Test, RM = repetition maximum, RPE = rating of perceived exertion, SPPB = Short Physical Performance Battery, SC = stair climbing, SQ = squat, STS = sit to stand, TUG = Timed Up and Go, UR = upright row, 6MWT = 6-minute walk test, reps = repetitions.

[a] Numerical data in the column are presented as: n, mean (SD), or range.

[b] Although calorie restriction was not formally prescribed, participants attend regular education sessions about healthy eating or a weight loss program.

interpretation of the result. In addition, assuming within-group correlation coefficients of 0.5 or 0.9 (instead of 0.7) did not influence the results from the meta-analyses on strength, physical function or power (see Table 3 on the eAddenda).

Meta-regressions

The results from the univariate meta-regressions are presented in Table 4. The effect of resistance training on strength was greatest for upper-body strength (versus lower/whole-body: β = 0.35, $p < 0.025$) and in dynamic tests (versus isometric/isokinetic: β = 1.20, $p < 0.001$), although trials judged to have good methodological quality reported smaller effects (versus poor/fair quality: β = −1.21, p = 0.039). Concomitant calorie restriction did not modify strength gains but reduced the effect of resistance training on physical function. That is, trials that included concomitant calorie restriction alongside resistance training reported smaller effects on physical function than studies without calorie restriction (β = −0.79, p = 0.015).

Discussion

This is the first review to quantitatively synthesise the effects of resistance training on muscle strength, power and physical function in adults who are overweight or obese. The results showed that resistance training leads to a large increase in muscle strength and moderate improvements in physical function, whilst the interval estimate for the effect of resistance training on muscle power showed high uncertainty. In addition, we found that concomitant calorie restriction reduced the effect of resistance training on physical function. These findings have important implications for healthcare providers and multidisciplinary teams involved in obesity management.

This review showed that resistance training has a large positive effect on muscle strength in adults who are overweight or obese. The 95% confidence interval around the standardised effect estimate (1.0 to 1.7) is encouraging because it suggests that the smallest SMD compatible with the data is still large. This is an important finding because it has previously been reported that excess adiposity reduces resistance training-induced adaptations. For instance, Pescatello et al[12] reported that normal-weight subjects (BMI 18.5 to 24.9 kg/m^2) increased isometric and 1RM elbow flexor strength significantly more than overweight subjects (BMI ≥ 25 kg/m^2) following 12 weeks of unilateral resistance training, despite similar increases in muscle size. More recent studies have also found that individuals with higher initial levels of subcutaneous adipose tissue[13] or intermuscular fat[11] gain strength at a slower rate compared with adults with lower adiposity. Nevertheless, the magnitude of pooled treatment effect in this review is slightly larger than the effects reported in meta-analyses involving apparently healthy adults (SMDs 0.84 to 1.08).[8–10] Thus, this finding provides strong support for resistance training as a countermeasure to obesity-related reductions in muscle strength.

Notwithstanding the removal of an influential study prior to conducting the meta-analysis,[37] there was still large heterogeneity between the SMDs on strength outcomes. This is likely due to differences in intervention characteristics (eg, duration, training load and training volume) and methodologies used to assess strength. Potential sources of heterogeneity were explored with meta-regressions, and it was found that the effects of resistance training were greater for tests of upper-body compared with lower-body and whole-body strength. It was also found that greater increases in strength occurred when the strength test was dynamic rather than isometric/isokinetic; a finding that is underpinned by the principle of specificity. The expression of strength is a specific skill that will improve the most when training closely reflects the test of strength. All resistance training interventions included in this review utilised dynamic exercises comprising concentric and eccentric muscular contractions. Thus, the muscle actions involved in conventional resistance training replicate the muscle actions involved in dynamic strength tests, such as the 1RM.

Another source of heterogeneity was methodological quality. Studies with good methodological quality reported smaller effects on strength compared with studies with poor or fair methodological quality. In addition, the funnel plot and Egger's regression test showed a strong positive relationship between the size of the SMD and the size of the sampling variance, which is suggestive of publication and/or reporting bias, amongst other issues.[67] Hence, the large treatment effect on strength reported in this review may be an overestimation of the true effect. To strengthen the evidence, future studies should aim to enhance the precision of their estimates (ie, by recruiting enough participants for adequate statistical power) and minimise sources of bias. In particular, randomised trials in this research area would benefit from reducing selection bias (concealing allocation), observer bias (blinding outcome assessors) and analysis bias (adhering to intention-to-treat principle).

It is well-established that diet-induced weight loss reduces absolute muscle strength in adults who are overweight or obese.[68] Interestingly, this review showed that calorie restriction does not influence the magnitude of strength gains in response to resistance training. Thus, resistance training can be included within a weight management program without a reduction in resistance training-induced gains in strength.

Maintaining the ability to perform activities of daily living is essential for preserving functional independence and quality of life. Poor physical function is associated with incident disability and a decreased motivation to exercise,[5,69] which impede regular engagement in physical activity and thus contribute to a perpetuating cycle of weight gain. The current meta-analysis showed that resistance training has a moderately beneficial effect on physical function in adults who are overweight and obese. Compared with muscle strength, the modest effect of resistance training on physical function may be due to the evidence of small study effects in strength outcomes, whereas there was no evidence for small study effects in physical function outcomes. There may also be a ceiling effect in the functional tests, whereby further increases in strength no longer lead to further improvements in function. Alternatively, it could be a consequence of the specificity of the exercise stimuli. Most trials included in this review involved single-joint exercises and/or the use of resistance machines, which limit the training movement to a fixed pattern in a single plane of motion. Whilst this regimen is effective for producing large increases in performance in strength tests, which are usually performed using the same equipment and motor pattern, it is likely to have a lesser impact on functional tasks such as the Timed Up and Go test and stair climbing.[70]

A key finding of this review was that calorie restriction negatively modified the effect that resistance training had on physical function. That is, combining resistance training with calorie restriction reduced the improvement in physical function compared with resistance training alone. Although not included in this review due to the absence of a non-exercising control group, this finding is in contrast to the results of Nicklas et al,[11] who showed that adding calorie restriction (600 kcal deficit/day) to resistance training elicited superior improvements in the 400-m walk test (MD 13 seconds) and self-reported disability on a 1-to-5 rating scale (MD 0.08) compared with resistance training alone. The current results suggest that practitioners should weigh up the relative importance of diet-induced weight loss versus improving physical function when developing an individual's weight management plan, and should be cautious when prescribing calorie restriction alongside resistance training when physical function is considered a primary endpoint for that individual.

In adults with obesity, the ability to generate power is reduced to a greater extent than strength.[71,72] Muscle power is also an important determinant of physical function in individuals who are severely obese.[73] However, although power appears to play an important role in the aetiology of obesity-related impaired function and in the performance of functional tasks, only two randomised trials have investigated the effects of resistance training on measures of power in adults who are overweight or obese. One study reported a significant effect of resistance training on leg press power,[44] whilst the other study observed no evidence of an effect,[28] leading to a pooled treatment effect that showed a high level of uncertainty. It is noteworthy that a set of studies is likely to contain a mix of significant and non-significant results, even if there is a positive effect.[74] Even so, more data from randomised trials are required to substantiate the effect of resistance training on muscle power.

There were some limitations to this review that deserve consideration. Only three trials in this review were classified as having good methodological quality. This, combined with low sample sizes and evidence of small study effects and high heterogeneity for strength outcomes, means that there was some uncertainty in the pooled

Table 2
PEDro scores of included studies.

Study	Eligibility and source	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% dropouts	Intention-to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total *(0 to 10)*
Avila 2010[28]	Y	Y	N	Y	N	N	N	Y	N	Y	N	4
Ballor 1988[29]	N	Y	N	Y	N	N	N	Y	N	Y	Y	5
Bouchard 2009[30]	Y	Y	N	Y	N	N	N	Y	N	Y	N	4
Davidson 2009[33]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Croymans 2014[31] and Roberts 2013[32]	Y	Y	N	N	N	N	Y	N	N	Y	Y	4
Donges 2013[34]	N	Y	N	Y	N	N	N	N	N	Y	Y	4
Fernandez-Real 2009[35]	Y	Y	N	Y	N	N	N	N	N	N	N	2
Figueroa 2013[36]	Y	Y	N	Y	N	N	N	Y	N	Y	N	4
Fritz 2018[37]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Herring 2014[38]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Hunter 2008[39,40]	N	Y	N	Y	N	N	N	N	N	Y	N	3
Hunter 2012[41]	N	Y	N	Y	N	N	N	N	N	Y	N	3
Kirk 2007[42]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Loria-Kohen 2013[43]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Marsh 2013[44]	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Messier 2010[45] and Normandin 2015[46]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Romero Moraleda 2013[47]	Y	Y	N	Y	N	N	N	N	N	N	N	2
Nikseresht 2014, 2016, 2018[48–51]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Olson 2007[52]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Rustaden 2017[53]	Y	Y	N	Y	N	N	Y	N	N	Y	Y	5
Saremi 2011[54]	Y	Y	N	Y	N	N	N	N	N	N	N	2
Sarsan 2006[55]	Y	Y	Y	Y	N	N	N	N	N	Y	Y	5
Tomeleri 2016[56]	Y	Y	N	Y	N	N	N	Y	Y	Y	N	5
Verreijen 2017[57]	Y	Y	Y	Y	N	N	N	N	N	Y	Y	5
Villareal 2017[58] and Colleluori 2019[59]	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Vincent 2006[60]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Warren 2008, 2009[62,66] and Schmitz 2007[61]	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	7
Wong 2019[63]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Wooten 2011[64]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Yoon 2018[65]	Y	Y	N	Y	N	N	N	N	N	Y	N	3

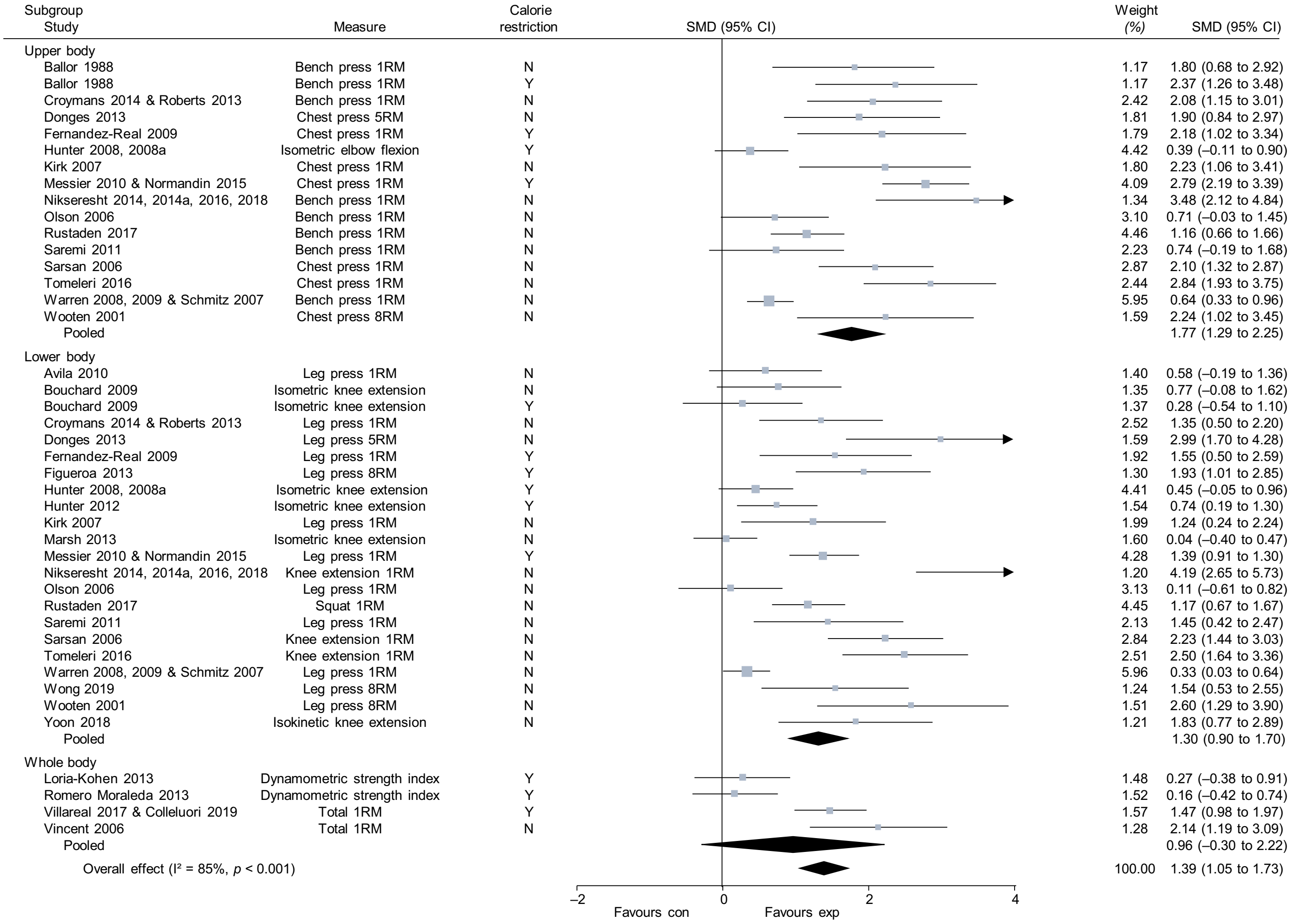

Figure 4. Forest plot of the results from a three-level random effects meta-analysis on the effects of resistance training on muscle strength.
Data are presented as standardised mean difference (SMD) between intervention and control groups with corresponding 95% confidence interval (CI).
Note that SMDs were nested within intervention groups to account for correlated effects within studies.[24]
1RM = one repetition maximum.

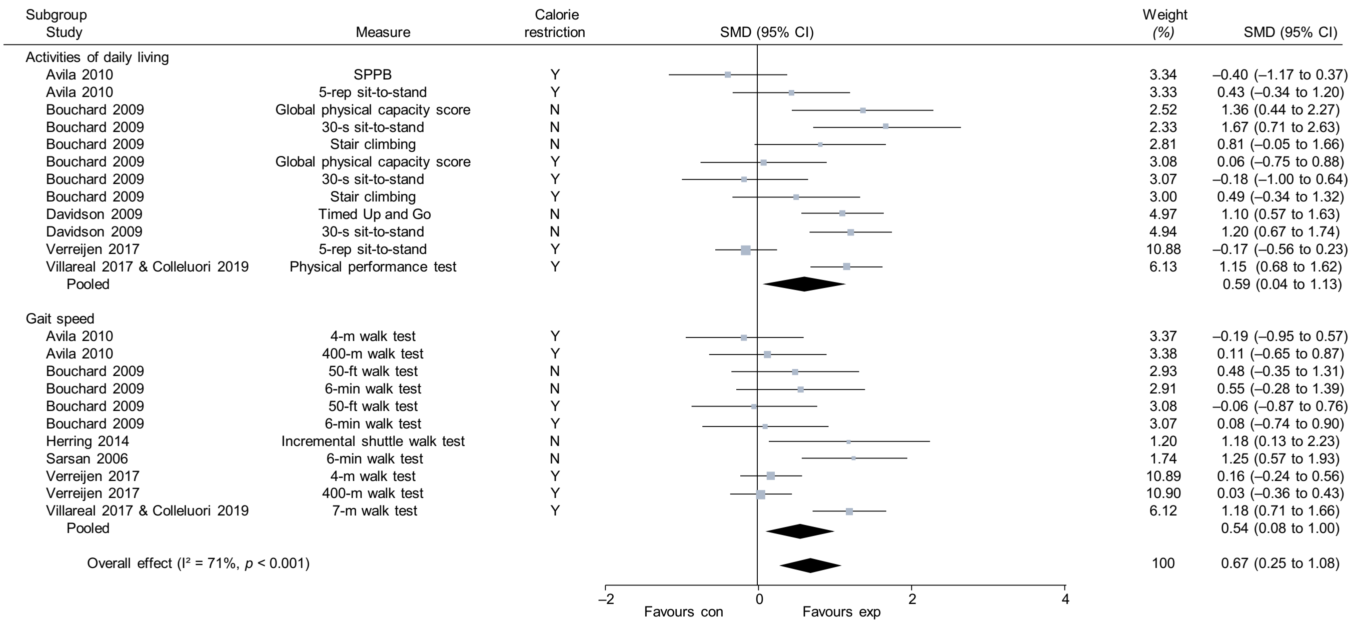

Figure 5. Forest plot of the results from a three-level random effects meta-analysis on the effects of resistance training on physical function.
Data are presented as standardised mean difference (SMD) between intervention and control groups with corresponding 95% confidence interval (CI).
Note that SMDs were nested within intervention groups to account for correlated effects within studies.[24]
SPPB = short physical performance battery.

Table 4
Meta-regression results.

Covariate	Strength			Physical function		
	N	Coefficient (95% CI)	I^2	N	Coefficient (95% CI)	I^2
Age	42	0.00 (−0.02 to 0.03)	85%	22	−0.01 (−0.07 to 0.04)	72%
Calorie restriction[a]	42	−0.42 (−1.12 to 0.28)	85%	23	−0.79 (−1.41 to −0.17)	54%
Methodological quality[b]	42	−1.21 (−2.35 to −0.07)	83%	23	0.57 (−0.54 to 1.68)	67%
Test type[c]	42	1.20 (0.60 to 1.81)	77%	23	−0.02 (−0.32 to 0.29)	71%
Muscle group[d]	42	0.35 (0.05 to 0.66)	84%	-		

[a] Calorie restriction is the covariate in the model, and the reference group is non-calorie restriction.
[b] Good methodological quality is the covariate in the model, and the reference group is the combination of poor and fair methodological quality.
[c] For strength outcomes, a specific test (eg, one repetition maximum) is the covariate in the model and the reference group is a non-specific test (eg, isometric or isokinetic). For physical function outcomes, gait speed is the covariate and the reference group is activities of daily living.
[d] Upper-body strength is the covariate in the model, and the reference group is the combination of lower-body and whole-body strength.

effect estimates. However, these estimates generally indicated marked effects, so clinical implications remain clear despite that uncertainty. In addition, the systematic search was limited to English-language manuscripts available in full text, and therefore may have missed some relevant trials.

To conclude, this review showed that resistance training has a large positive effect on muscle strength and a moderate positive effect on physical function in adults who are overweight or obese. In contrast, the interval estimate for the effect of resistance training on muscle power shows a high level of uncertainty, primarily due to the low number of studies that have measured power as an outcome. Our results also suggest that calorie restriction does not modify strength gains, but may compromise the effect of resistance training on physical function. These findings support the inclusion of resistance training within multidisciplinary weight management programs to counteract obesity-related reductions in relative strength and physical functioning. Further high-quality evidence is required to increase the certainty of the effect estimates.

What was already known on this topic: Adults who are overweight or obese have lower relative muscle strength and power than their lean counterparts. This reduces physical function, which may decrease motivation to exercise and thus contribute to a perpetuating cycle of inactivity and weight gain. **What this study adds:** In adults who are overweight or obese, resistance training has a large positive effect on muscle strength and a moderate positive effect on physical function, but its effect on muscle power remains unclear. Adding calorie restriction to the resistance training may compromise its effect on physical function.

Footnotes: [a] Excel, Microsoft Corporation, Redmond, USA. [b] R Version 3.5.2, R Foundation for Statistical Computing, Vienna, Austria.

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