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SYSTEMATIC REVIEW

The Effect of Resistance Training in Healthy Adults on Body Fat Percentage, Fat Mass and Visceral Fat: A Systematic Review and Meta-Analysis

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Abstract

Background Resistance training is the gold standard exercise mode for accrual of lean muscle mass, but the isolated effect of resistance training on body fat is unknown.

Objectives This systematic review and meta-analysis evaluated resistance training for body composition outcomes in healthy adults. Our primary outcome was body fat percentage; secondary outcomes were body fat mass and visceral fat.

Design Systematic review with meta-analysis.

Data Sources We searched five electronic databases up to January 2021.

Eligibility Criteria We included randomised trials that compared full-body resistance training for at least 4 weeks to no-exercise control in healthy adults.

Analysis We assessed study quality with the TESTEX tool and conducted a random-effects meta-analysis, with a subgroup analysis based on measurement type (scan or non-scan) and sex (male or female), and a meta-regression for volume of resistance training and training components.

Results From 11,981 records, we included 58 studies in the review, with 54 providing data for a meta-analysis. Mean study quality was 9/15 (range 6–15). Compared to the control, resistance training reduced body fat percentage by −1.46% (95% confidence interval −1.78 to −1.14, $p<0.0001$), body fat mass by −0.55 kg (95% confidence interval −0.75 to −0.34, $p<0.0001$) and visceral fat by a standardised mean difference of −0.49 (95% confidence interval −0.87 to −0.11, $p=0.0114$). Measurement type was a significant moderator in body fat percentage and body fat mass, but sex was not. Training volume and training components were not associated with effect size.

Summary/Conclusions Resistance training reduces body fat percentage, body fat mass and visceral fat in healthy adults.

Study Registration osf.io/hsk32.

1 Introduction

Resistance training (RT) is a popular mode of exercise with numerous benefits not as readily obtained through other modes of exercise (e.g. aerobic exercise), such as preserving

Key Points

Resistance training elicits average reductions of 1.4% body fat percentage and 0.55kg body fat mass compared with non-exercise control.

Resistance training elicits moderate reductions in visceral fat compared with non-exercise control.

Measurement type (scan or non-scan) may influence the magnitude of body composition changes, but not sex (male or female) or total training volume

The magnitude of reduction in adiposity observed in this review is similar to previous reviews utilising different exercise modalities.

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bone mineral density [1] and increasing lean body mass [2]. It also plays a role in the prevention or symptom management of many chronic diseases [3, 4], and therefore physical activity guidelines recommend participating in RT 2–3 days per week [5].

While it is clear RT elicits improvements in lean body mass [6, 7], effects on other body composition outcomes (such as subcutaneous fat and visceral fat) are less clear. The American College of Sports Medicine position stand on physical activity for weight loss and prevention of weight regain [8] states that RT will not promote clinically significant weight loss, and may increase losses of body fat mass only when combined with aerobic exercise [8]. Importantly, this position stand is made in the context of weight loss, not participation in RT for health or performance. When considering the effect of RT on subcutaneous fat, the evidence is varied [8]. This may be because of differences in the study design such as the inclusion of concurrent interventions [9], or owing to the use of differing methodologies when analysing body composition [10]. Interestingly, RT appears to preferentially mobilise visceral fat in overweight and obese individuals [11] but the magnitude of this effect is unknown. Visceral fat exerts more negative metabolic and health consequences than subcutaneous fat [12]; therefore, any intervention that reduces visceral fat may have clinical relevance and may be important in cohorts of both normal weight and those overweight or obese.

It is generally accepted in the industry, but less so in the scientific literature, that RT may promote body composition changes in addition to accrual of lean mass. The concept of concomitantly reducing body fat mass and gaining lean mass has been termed body 'recomposition' [13]. Given that higher levels of lean mass are associated with a lower risk of all-cause mortality [14], body recomposition is arguably more important than simply reducing body mass in healthy individuals. As such, this review aimed to determine whether RT changes whole-body fat and visceral fat in healthy adults.

2 Methods

2.1 Protocol, Registration and Data Availability

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 statement [15]. The PRISMA checklist is available in the Electronic Supplementary Material (ESM). We pre-registered the review protocol on the Open Science Framework on 4 June, 2020, prior to commencing the literature search (osf.io/hsk32). The data and *R* script used in the meta-analysis are also available on the Open Science Framework.

2.1.1 Deviations from Protocol

We conducted an additional post-hoc meta-regression to examine the relationship between the baseline value for each outcome and the effect size. Further details are provided in Sect. 2.8.

2.2 Eligibility Criteria

2.2.1 Study Design

We included English-language parallel randomised trials and the first phase of crossover trials published in peer-reviewed academic journals. We excluded cluster trials.

2.2.2 Participants

We included studies that examined apparently healthy adults with no known medical conditions/injuries who were not currently participating in RT and were not performing additional structured physical activity outside of the intervention (e.g. athletic populations with concurrent training). We included studies of overweight/obese adults provided other chronic diseases or risk factors were not present. If people with chronic disease or risk factors were incidentally recruited, we excluded studies where > 20% of participants presented with a given condition (e.g. hypertension). Medication usage was also considered as a surrogate for the presence of a chronic disease risk factor when judging eligibility.

2.2.3 Intervention and Comparator

We included studies that compared a whole-body RT intervention conducted for at least 4 weeks to a non-exercise control. Resistance training interventions must have used a dynamic machine or free weight-based constant, external loads, and included at least one upper and one lower body exercise in the overall programme. We excluded studies that exclusively utilised bodyweight exercises and studies with concurrent nutritional interventions or additional exercise (e.g. aerobic exercise or team sport training).

2.3 Outcomes

Our pre-specified primary outcome was the change in body fat percentage (measured in %) from baseline to the closest timepoint following the intervention. Our secondary outcomes were change in body fat mass (measured in kg) and change in visceral fat (measured in cm^2, cm^3, kg).

For body fat percentage and body fat mass, we considered measurements in the following hierarchy: dual-energy x-ray

absorptiometry (DXA), magnetic resonance imaging (MRI), computerised tomography (CT), hydro-densitometry or whole-body air plethysmography. We excluded other measurements (e.g. bioimpedance analysis or skinfolds) because of the lack of measurement reliability and the lack of sensitivity to detect change [16]. For visceral fat, we considered measurements from DXA, MRI, or CT because hydro-densitometry and plethysmography cannot estimate visceral fat.

2.4 Literature Search

We searched five electronic databases (MEDLINE, Embase, Cochrane CENTRAL, SPORTDiscus and CINAHL) up to January 2021. The complete search strategy for MEDLINE was the following: ("Resistance exercise" OR "Resistance training" OR "Strength training" OR "Strength Exercise" OR "Weightlifting" OR "Weight training") AND ("RCT" OR "randomised" OR "random"). We also looked for trials from relevant previous systematic reviews.

All authors screened records. Following duplicate deletion, two authors independently screened each record for eligibility by title/abstract and, if required, full text using Covidence [17]. Discrepancies were resolved via discussion, and arbitration from the senior author (ADH) as required. We collated multiple records reporting on the same data into a single study. For every included study in our review, we also searched the reference list and conducted forward citation tracking with Google Scholar to ensure a thorough literature search.

2.5 Data Extraction

All authors extracted data. Two authors independently extracted descriptive and outcome data from each study into custom spreadsheets. Discrepancies were resolved via discussion. For all outcomes, we preferentially extracted the change from baseline for intervention and control as mean and standard deviation (SD). We converted the percentage change from baseline into appropriate values in four studies [18–21]. We converted other measures of variability (e.g. standard error or 95% confidence intervals [CI]) to SD following guidance from section 6.5.2.3 of the *Cochrane Handbook* [22]. We converted median and interquartile for two studies [23, 24] to mean and SD using published equations [25]. If a study comprised multiple eligible resistance interventions, we split the control group sample proportionately [22].

If a change from baseline data was not reported, we extracted the baseline and post-intervention data and calculated the change from the baseline as post-intervention mean minus pre-intervention mean. We calculated SD for change using an estimated pre-/post-intervention correlation, following guidance from section 6.5.2.8 of the *Cochrane Handbook* [22]. As correlations are seldom reported, we identified all studies in our review that reported information sufficient to calculate a correlation, then imputed the median correlation derived for each outcome. We used a median correlation from four studies of 0.96 for body fat percentage (mean = 0.96, range 0.91–0.97), a median correlation from five studies of 0.95 for body fat mass (mean = 0.95, range 0.89–0.97) and a correlation from one study of 0.97 for visceral adipose tissue (range 0.97–0.98).

We did not extract any data from figures. We contacted the corresponding authors of four studies that reported insufficient data for extraction [26–29]. We received no response following author contact; therefore, we did not use any data from these studies in the meta-analysis. We contacted the corresponding authors of 15 studies for sex-disaggregated data and received data from five (33%).

2.6 Quality Assessment

We evaluated the quality of each included study using the Tool for the assEssment of Study qualiTy and reporting in EXercise (TESTEX) [30]. Two authors independently assessed each study across 15 criteria, each worth one point, with discrepancies were resolved via discussion. We did not classify scores as "high" or "low" (or some other arbitrary grouping) because of the limitations associated with these approaches [31].

2.7 Data Synthesis

We performed a random-effects meta-analysis in R (version 4.0.4) using the *metafor* package (version 2.4) [32]. For body fat percentage and absolute body fat, we calculated the pooled mean difference between RT and control groups with 95% CIs. For visceral adipose tissue, we calculated the standardised mean difference with 95% CIs to account for the variety of measurement units. We quantified heterogeneity using a restricted estimate maximum likelihood model with the 95% prediction interval, Cochran Q, tau (τ^2) and I^2. We used conventional and contour-enhanced funnel plots to illustrate possible publication asymmetry/bias, and if more than ten studies were available we conducted Egger's regression test ($\alpha < 0.10$ indicating the presence of asymmetry).

2.8 Additional Analyses

We conducted pre-planned subgroup analyses to examine the moderating effects of measurement type (scan: DXA, MRI, CT; or non-scan: hydro-densitometry, whole-body air plethysmography) and sex (male or female). We also conducted

a pre-planned meta-regression to examine the moderating effect of total training volume during an intervention, with the hypothesis that increased training volume would be related to greater reductions in body fat and visceral fat. We considered total training volume as:

Study duration (weeks) multiplied by weekly training volume (calculated as frequency [days per week] × intensity [% 1 repetition maximum (RM)] × number of sets per session × number of repetitions per set).

If a range of values was used (e.g. 2–3 days per week, or 8–12 repetitions per set), we used the mean value (e.g. 2.5 and 10, respectively). When intensities were reported as a RM, we converted to %1RM via an estimated repetition at a %1RM chart [33]. If prescriptive parameters were unclear, we imputed the mean value from other studies: number of exercises = 8 (required for four studies [34–36]); number of sets = 2.6 (required for one study [37]). We excluded two studies [38, 39] (three comparisons) from this meta-regression because both studies completed as many repetitions as possible in each set.

We also conducted a post-hoc meta-regression to examine the moderating effect of baseline values, hypothesising that higher values at baseline would be associated with greater reductions in body fat and visceral fat. We combined the baseline means from the intervention and control groups using the formula from Table 6.5a in section 6.5.2.10 of the *Cochrane Handbook* [22]. Based on recommendations during peer review, we also conducted a post-hoc meta-regression to examine the moderating effect of study duration (weeks), frequency of sessions (days/week), intensity (%1RM) and total sets per week (number of sets × number of exercises × frequency).

3 Results

Our literature search is illustrated in Fig. 1. We screened 11,981 records and assessed 463 full-text articles for eligibility. Seventy-five included records formed 56 included studies following record collation. We identified two additional studies during citation tracking, ultimately resulting in 58 studies included in the review [18–21, 23, 24, 26–29, 34–81] (Table 1 of the ESM). Four of these studies failed to respond to e-mail requests for data [26–29]. Therefore, 54 studies were included in the meta-analysis [18–21, 23, 24, 34–81]. Fourteen studies investigated multiple resistance training interventions.

The number of participants randomised was 3058 (reported across 56 studies): 1232 male patients (40.3%), 1722 female patients (56.3%) and 104 with sex not reported (3.4%). Participants were on average 51.2 years of age (mean ages ranged from 19 to 72.1 years). No participants were experienced in RT, with baseline activity levels from sedentary to recreationally active.

Resistance training interventions (Table 2 of the ESM) were typically conducted at universities and supervised by qualified instructors. They were conducted for an average of 20.5 weeks (range 6–104 weeks), with an average frequency of 2.7 sessions per week (range 1–4 weeks). The average number of exercises per session was 8.1 (range 4–15), with most studies outlining the specific exercises; sets averaged 2.6 per session per exercise (range 1– 5) and repetitions averaged nine per set (range 5–15). Intensities were typically quantified through %1RM. Almost every study clearly reported progression through some means.

3.1 Study Quality

Included studies scored an average of 9 (SD = 2) out of 15 on the TESTEX (median = 8; range 6–15). As illustrated in Fig. 2, few studies included adequate reporting of allocation concealment (6%), intention-to-treat analysis (6%), assessor blinding (15%), random sequence generation (19%), control group monitoring (26%) and adverse events (32%). The majority of studies adequately reported point estimates (95%), between-group comparisons for the primary outcome (94%) and a secondary outcome (92%), consistent exercise intensity (90%), baseline similarity (89%), inclusion criteria (84%), sufficient prescriptive detail for the calculation of exercise volume (79%), adherence > 85% (69%) and session attendance (53%).

3.2 Body Fat Percentage

Data for body fat percentage were available from 41 studies (52 comparisons with 1506 participants: RT = 875; control = 631). We excluded six studies [26–29, 45, 77] (ten comparisons) with insufficient data. Resistance training reduced body fat percentage by − 1.46% (95% CI − 1.78 to − 1.14, $p < 0.0001$) (Fig. 3). Significant heterogeneity was apparent ($Q = 155.19$, $p < 0.0001$; $I^2 = 83\%$), with the 95% prediction interval spanning − 3.20 to 0.29. Our subgroup analysis demonstrated both scan and non-scan subgroups were associated with reductions in body fat percentage; non-scan displayed a significantly larger effect than scan (between-subgroup difference = 1.4% [95% CI 2.0–0.8], $p < 0.0001$). Heterogeneity was not evident in the scan subgroup ($Q = 35.15$, $p = 0.65$; $I^2 = 12\%$), but substantial heterogeneity remained in the non-scan subgroup ($Q = 60.57$, $p < 0.0001$; $I^2 = 97\%$).

Sex-disaggregated data were available from 23 female-only comparisons (648 participants: resistance training = 368; control = 280) and 24 male-only comparisons (591 participants: resistance training = 332; control = 259). As shown in Fig. 1 of the ESM, RT reduced body fat percentage in female-only

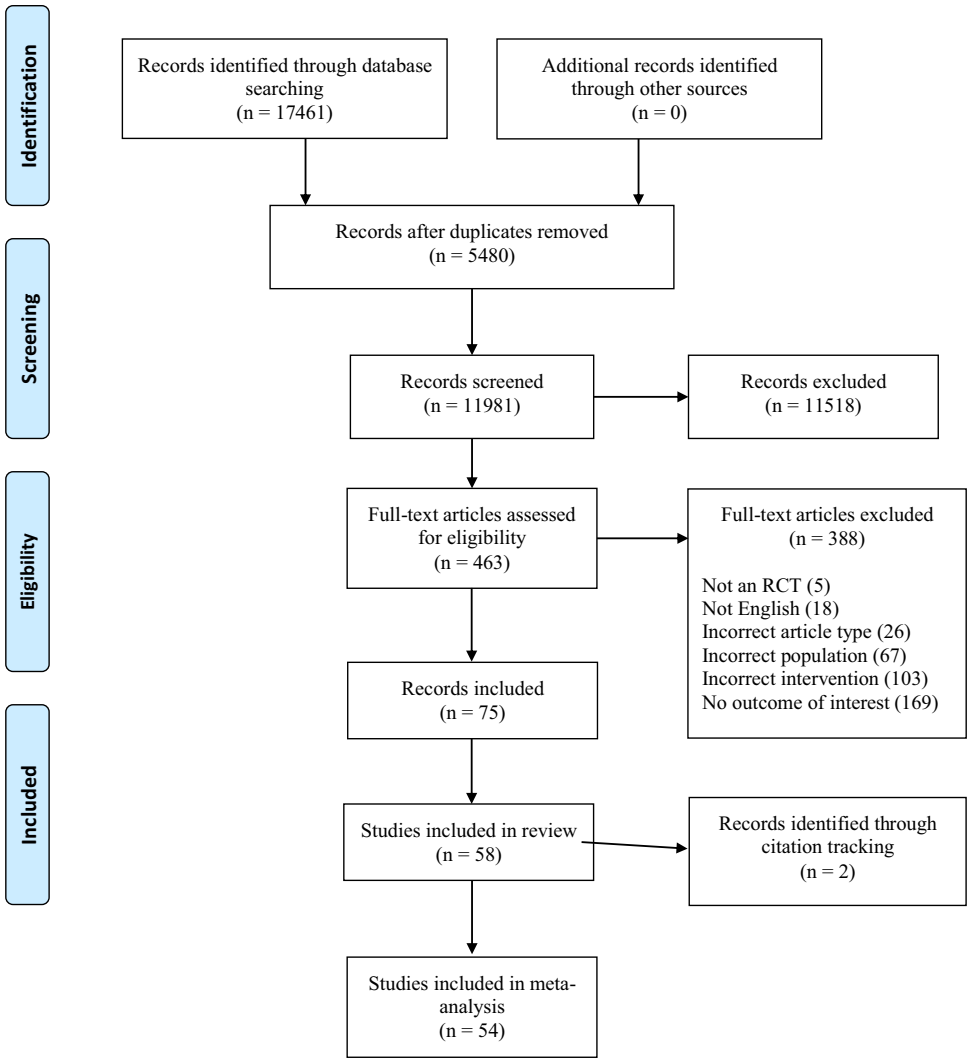

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

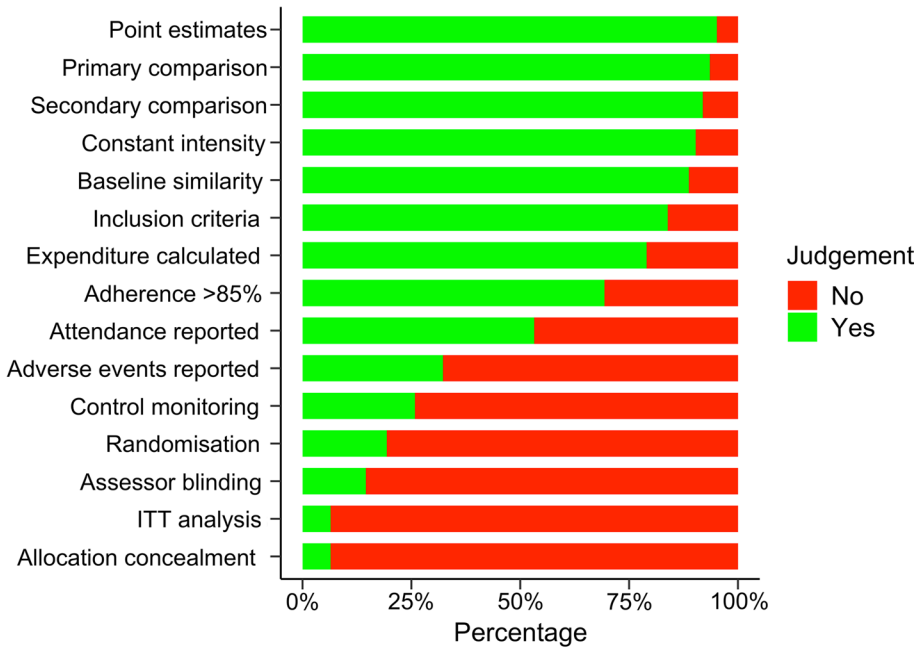

Fig. 2 Study quality, according to the TESTEX tool. *ITT* intention-to-treat

comparisons by −1.53% (95% CI −2.14 to −0.91, $p<0.0001$) and in male-only comparisons by −1.46% (95% CI −1.79 to −1.12, $p<0.0001$). There was no difference between subgroups (0.13% [95% CI −0.58 to 0.84], $p=0.72$).

Our pre-planned meta-regression demonstrated no association between total training volume and effect size: $\beta=0.0$ (95% CI 0.0–0.0), $p=0.31$. Our post-hoc meta-regression also demonstrated no association between baseline value and effect size: $\beta=0.03$ (95% CI 0.0–0.06), $p=0.07$. Additional meta-regression analyses did not find associations for study duration, session frequency, intensity or total sets per week (Table 3 of the ESM).

3.3 Body Fat Mass

Data for body fat mass were available from 36 studies (53 comparisons with 1638 participants: resistance training = 960; control = 668). We excluded three studies [26, 28, 29] (four comparisons) with insufficient data. Resistance training reduced body fat mass by −0.55 kg (95% CI −0.75 to −0.34, $p<0.0001$) (Fig. 4). No heterogeneity was apparent ($Q=51.20$, $p=0.51$; $I^2=2.6\%$), with the 95% prediction interval spanning −0.86 to −0.26. Our subgroup analysis demonstrated both scan and non-scan subgroups were associated with reductions in body fat mass; non-scan displayed a significantly larger effect than scan (between-subgroup difference = 1.15 kg [95% CI 0.29–2.0], $p=0.009$).

Sex-disaggregated data were available from 28 female-only comparisons (847 participants: resistance training = 497; control = 350) and 23 male-only comparisons (593 participants: resistance training = 329; control = 264). As shown in Fig. 2 of the ESM, RT reduced body fat mass in female-only comparisons by −0.35 kg (95% CI −0.60 to −0.09, $p=0.008$) and in male-only comparisons by −0.69 kg (95% CI −1.03

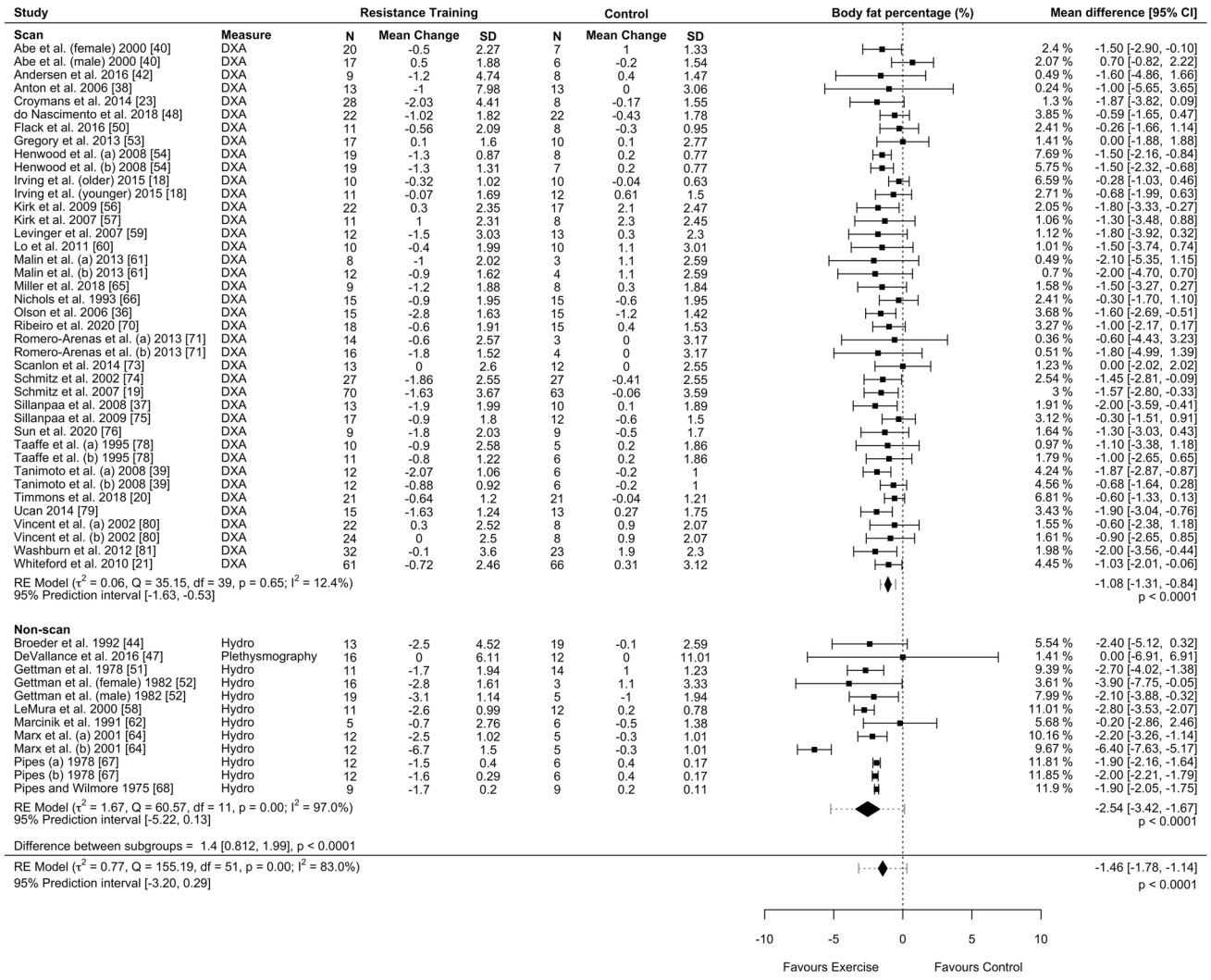

Fig. 3 Forest plot of body fat percentage. a, b, c different resistance training arms from a study that share the same control group, *CI* confidence interval, *DXA* dual x-ray absorptiometry, *N* number of participants, *RE* random effects, *SD* standard deviation

to −0.34, $p < 0.0001$). There was no difference between subgroups (−0.29 [95% CI −0.69 to 0.11], $p = 0.16$).

Our pre-planned meta-regression demonstrated no association between total training volume and effect size: $\beta = 0.0$ (95% CI 0.0–0.0), $p = 0.63$. Our post-hoc meta-regression also demonstrated no association between baseline value and effect size: $\beta = 0.0$ (95% CI 0.0–0.0), $p = 0.27$. Additional meta-regression analyses did not find associations for study duration, session frequency, intensity or total sets per week (Table 3 of the ESM).

3.4 Visceral Fat

Data for visceral fat were available from four studies (four comparisons with 216 participants: resistance training = 111; control = 105). There were no missing data. Measurement units included volume (cm^3), mass (kg) and area (cm^2). Resistance training reduced visceral fat by a standardised mean difference of −0.49 (95% CI −0.87 to −0.11, $p = 0.011$) (Fig. 5). Minimal heterogeneity was apparent ($Q = 4.53$, $p = 0.21$; $I^2 = 32.5\%$), with the 95% prediction interval spanning −1.07 to 0.09.

Sex-disaggregated data were available for all studies: three female-only comparisons (212 participants: resistance training = 109; control = 103) and one male-only comparison (four participants: resistance training = two; control = two). As shown in Fig. 3 of the ESM, resistance training reduced visceral fat in female-only comparisons by a standardised mean difference of −0.48 (95% CI −0.86 to −0.10, $p = 0.0142$). We did not assess between-subgroup differences because of a lack of data.

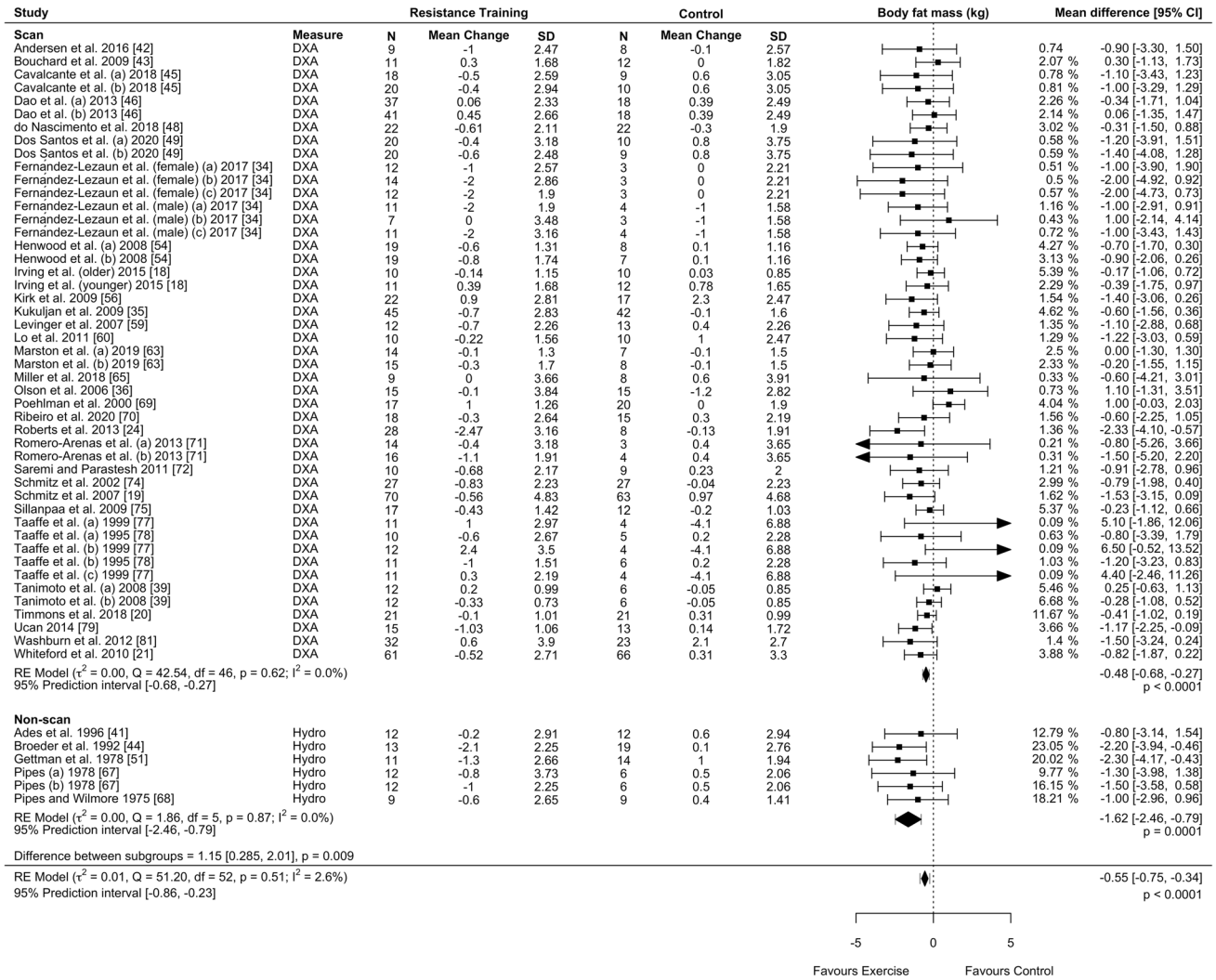

Fig. 4 Forest plot of body fat mass. a, b, c different resistance training arms from a study that share the same control group, *CI* confidence interval, *DXA* dual x-ray absorptiometry, *N* number of participants, *RE* random effects, *SD* standard deviation

Our pre-planned meta-regression demonstrated no association between total training volume and effect size: $\beta = 0.0$ (95% CI 0.0–0.0), $p = 0.78$. Our post-hoc meta-regression also demonstrated no association between baseline value and effect size: $\beta = 0.0$ (95% CI 0.0–0.0), $p = 0.79$. We did not perform additional meta-regression analyses because of limited data.

3.5 Publication Bias

Conventional and contour-enhanced funnel plots are available in Figs. 4–6 of the ESM. Visual inspection did not indicate publication asymmetry, which was also indicated by Egger's regression test for fat mass percentage ($z = 0.51$, $p = 0.61$) and body fat mass ($z = -1.30$, $p = 0.19$).

4 Discussion

Our results show that RT elicits significant reductions in body fat percentage, body fat mass and visceral fat in healthy adults. This provides evidence for the notion of body recomposition and adds to the previous literature demonstrating benefits of RT [6, 7]. Body recomposition, rather than simply decreases in body mass, may therefore be the more appropriate goal of an RT exercise programme for healthy individuals. A clinically meaningful decrease of 3–5% of body mass is used in overweight and obese individuals and relates to health outcomes [8, 82]. However, when considering healthy individuals (particularly those within a healthy range for body mass), the components of body composition become more relevant.

Resistance training reduced body fat percentage by 1.4% in our review, a magnitude that is comparable to other modes of exercise. A previous meta-analysis of aerobic exercise modalities by Keating et al. [83] determined that high-intensity/sprint interval training and moderate-intensity continuous training reduced body fat percentage by 1.26% and 1.4%, respectively. However, the reduction in body fat mass of 0.55 kg in our review is smaller than the 1.38-kg or 0.91-kg reductions determined by Keating et al. for high-intensity/sprint interval training and moderate-intensity continuous training, respectively, suggesting that different types of training elicit different body composition adaptations. Previous reviews have shown that RT typically increases lean mass by approximately 1.5 kg [6, 7], although several factors can influence the magnitude of adaptation such as the intake of protein [84] and creatine [85]. Therefore, although not examined in our review, individuals participating in RT interventions in our review probably gained muscle mass and the changes in body fat percentage may reflect the accrual of lean mass unlikely to be experienced in the aerobic-based modalities. Similarly, RT participation during a weight loss programme conserves lean mass [86, 87], while no exercise [86] or aerobic exercise [86, 87] leads to losses in lean mass. Therefore, given RT appears to elicit similar reductions in adiposity as other exercise modes, yet has the added benefit of lean mass accrual, it should be considered a valuable component of weight loss interventions in overweight or obese individuals.

Importantly, we excluded studies with concurrent weight loss interventions (caloric restriction, dietary alteration, supplementation or concurrent aerobic exercise), suggesting our findings are 'incidental' body composition changes, as they were not the intent of the intervention. The long-term average weight gain in adulthood has been estimated to be 0.5–0.8 kg per year, primarily due to increases in fat mass [88]. Therefore, RT may be sufficient to offset some

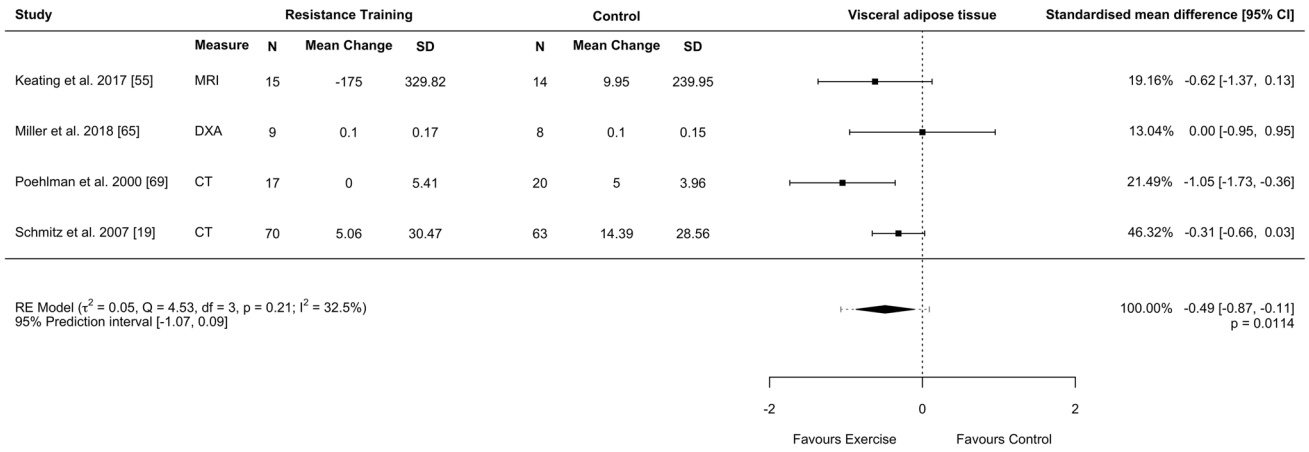

Fig. 5 Forest plot of visceral fat. a, b, c different resistance training arms from a study that share the same control group, *CI* confidence interval, *CT* computed tomography, *DXA* dual x-ray absorptiometry, *MRI* magnetic resonance imaging, *N* number of participants, *RE* random effects, *SD* standard deviation

age-related alterations in body composition, but this effect would likely be even greater if combined with additional interventions (e.g. dietary interventions).

Visceral fat is important because of its negative association with many facets of health [12]. Our review found that RT conferred moderate reductions in visceral fat. Our findings contrast with those of Ismail et al. [89], who found that aerobic exercise, but not RT, significantly reduced visceral fat, and Maillard et al. [90], who found that high-intensity interval training reduced visceral fat in overweight or obese adults, but not in individuals with normal weight. There are numerous differences between the reviews that may explain the discrepant findings. For example, both Maillard et al. [90] and Ismail et al. [89] included cohorts with disease who may be performing different exercise interventions from those applied to healthy populations, and thus experiencing differing levels of adaptation. When we consider the notion of body recomposition, our findings suggest RT may elicit more favourable changes for healthy adults than participating in only aerobic exercise (in terms of both accrual of lean mass, and reductions in fat mass including visceral fat).

It is interesting to note effect sizes in body fat percentage and body fat mass were associated with measurement type, with effect sizes from scan measurements significantly smaller than effects from non-scan measurements. Studies with non-scan measurements in our review also appeared to drive the heterogeneity in the outcomes of body fat percentage and body fat mass. Scan measurements (DXA, MRI and CT) are more accurate than other types [16], which suggests body composition assessment methods must be considered in meta-analyses of exercise (and possibly other intervention types). Previous reviews have included non-scan measurements (bioelectrical impedance, skinfolds, hydro-densitometry or air displacement plethysmography) [83] and therefore their results may, to some extent, be an overestimation. Our strict inclusion criterion for outcome measurement increases the confidence in the accuracy of our effect and is a strength of our review because we excluded measurement tools with large variability. However, we noted that testing standardisation was poorly reported in our included studies and there is a possibility that some of the observed changes may be due to measurement error. Acute changes due to food and fluid intake do not influence scan-based assessments of body fat mass but do influence lean muscle mass, and therefore would influence the body fat percentage [91]. It is imperative that future studies adhere to testing standardisation protocols and adequately report on these protocols to ensure confidence in data interpretation. The other subgroup analysis in our review suggests no difference between male and female patients, and our meta-regressions did not find effect sizes were associated with training volume or baseline values.

The exact mechanisms by which RT elicits fat loss in our review are unclear. The concept of excess post-exercise oxygen consumption (EPOC) is related to the excess energy required to return the body to its normal resting state following exercise and has been postulated to contribute to body composition changes. The magnitude and duration of EPOC appear to be related to exercise duration and intensity [92]. Excess post-exercise oxygen consumption following RT has typically been shown to be negligible, and only lasts approximately 60 min following RT [93]. However, this is not always the case, with some research demonstrating that EPOC remains elevated for up to 38 h following RT in male patients [94]. There is also a wide variability in the duration of time in which EPOC may remain elevated with the largest decline towards baseline values occurring in the first 14 h following exercise [94]. Multiple prescriptive factors may influence the magnitude of EPOC observed. The amount of active muscle is likely to contribute to EPOC [95], and to the overall energy expenditure of the RT session. When RT volume is matched, EPOC has been shown to be greater following high-intensity RT compared with low-intensity RT despite similar within-exercise energy consumptions [96]. However, this difference was negligible by 20 min and, as such, is unlikely to contribute to alterations in body composition. Similarly, the volume of work done during a RT session affects the energy expenditure during the actual session, but does not influence post-exercise energy expenditure [97]. It has been suggested that many RT studies that report high EPOC values may overestimate its true effect due to methodologies employing acute exercise bouts [98] aiming to elicit a large degree of muscle damage that are not reflective of an ecologically valid RT programme [93, 98]. While EPOC is indeed a recognised physiological phenomenon, at present, there is insufficient evidence demonstrating EPOC as a key determinant in altering body composition [99]. The effect of EPOC on weight loss is suggested to be negligible, with the effect of exercise likely due to the energy expended during the exercise sessions [100, 101].

Resting metabolic rate (RMR) is the largest contributor to total daily energy expenditure [102] and, as such, it is plausible that RMR may influence body composition. A recent systematic review and meta-analysis examined the effect of differing exercise interventions on RMR [103]. This study found that combined aerobic and resistance training interventions, and aerobic-only interventions, did not increase RMR. The authors found that RT increased RMR compared with controls by a mean difference of 96.17 kcal per day [103]. While these differences were deemed statistically significant, the clinical relevance of an increase of this magnitude is less clear. In a cohort of overweight women, following 20 weeks of RT, the women gained an average of 1.9 kg of fat-free mass and increased their RMR by a corresponding 44 kcal per day [104]. However, although exercise can elicit increases in fat-free mass, a change in RMR

does not always occur [102]. It is important to differentiate here that the concept of 'maintaining' RMR via RT during a weight loss programme is different from an RT programme conducted for other outcomes, as was the focus of the studies included in this review. Similar to the influence of EPOC on weight control and fat loss, the effect of RMR also appears to be negligible, with the benefit likely also arising predominantly from the exercise bout itself.

Perhaps, if fat loss is the goal of the exercise programme, then prescriptive modifications could focus on maximising energy expenditure within a given session. For example, super slow RT has been shown to be less metabolically demanding and create a lower overall energy expenditure than traditional RT [105]. The energy cost of traditional RT ranges significantly from 179 cal (inclusive of the 30-min session plus 15 min of recovery) [105] to approximately 300 cal following a body pump or high-intensity lifting session lasting approximately 1 h [98].

At this point, our understanding of 'how' resistance training should be prescribed to maximise fat loss is not defined. Our meta-regressions demonstrated no influence from the training variables duration, frequency, intensity or weekly set volume. From a pragmatic standpoint, it is likely that the interplay of these prescriptive parameters will influence the metabolic demands of the RT programme, and the subsequent body composition alterations. Farinatti et al. [106] conducted a systematic review examining the effect of RT variables on EPOC and found that RT volume influenced the magnitude and duration of EPOC, yet load influenced the magnitude. These authors recommended that high-intensity RT, performed in a circuit-style manner, would likely have the biggest influence on EPOC [106]. Again, it must be noted that this study focused on the prescriptive variables' influence on EPOC, which does not necessarily translate to weight loss. However, this type of prescription may indeed elicit a greater energy expenditure in a shorter time period, i.e. be more efficient than traditional heavy RT with long rest periods. Ultimately, the prescription will be based on the individuals' goals for the training programme.

Our review is not without limitations. We conducted a thorough literature search but did exclude languages other than English; however, but based on previous research we believe this will have minimal impact on our results [107]. We were also limited by the need to impute variance estimates for several studies and exclude data from four studies as a last resort. However, we undertook a valid approach to overcome these issues and attempted to adhere to principles of open science. To improve the confidence in their results, future studies should focus on better conduct and reporting of allocation concealment, intention-to-treat analysis, assessor blinding, random sequence generation, control group monitoring and adverse events.

5 Conclusions

In summary, we found that RT moderately decreased body fat percentage, fat mass and visceral fat in healthy adults. The changes after RT are incidental in nature and are likely combined with greater body recomposition benefits including gains of lean mass. A 3–5% recomposition may have importance and relevance for normal weight individuals participating in an RT programme.

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Declarations

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Conflict of interest Michael Wewege, Imtiaz Desai, Cameron Honey, Brandon Coorie, Matthew Jones, Briana Clifford, Hayley Leake and Amanda Hagstrom declare that they have no conflicts of interest relevant to the content of this review.

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Consent to participate Not applicable.

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Availability of data and material The data used in this study are available on the Open Science Framework (osf.io/hsk32). All *R* packages are available via the Comprehensive R Archive Network.

Code availability The *R* script used in this study is available on the Open Science Framework (osf.io/hsk32).

Author contributions ADH was responsible for the review design and team management, the literature search and drafting of the manuscript. All authors participated in screening and data extraction. MAW conducted the statistical analysis and reported its results. All authors approved the final version of the manuscript.

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