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SYSTEMATIC REVIEW

What is the Effect of Resistance Training on the Strength, Body Composition and Psychosocial Status of Overweight and Obese Children and Adolescents? A Systematic Review and Meta-Analysis

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Abstract

Background Overweight and obese children and adolescents face many physical and psychosocial hardships. Resistance training is a modality of exercise which allows this at-risk group to excel and therefore has the potential to positively affect not only their physical but also psychosocial health.

Objective To systematically review and meta-analyse the peer-reviewed literature to determine the effect of resistance training on the strength, body composition and psychosocial status of overweight and/or obese children and/or adolescents.

Data Sources Relevant databases (MEDLINE, Embase, Scopus, Web of Science, SPORTDiscus, CINAHL, PsycINFO, Cochrane library, ProQuest) were searched up to and including 30 January 2013.

Study Selection Included studies ($n = 40$, from the 2,247 identified) were randomised controlled trials (RCTs), non-randomised controlled trials (NRCTs) and uncontrolled trials (UCTs) which had run an exercise intervention, with a resistance training component, for overweight and/or obese children and/or adolescents, and which had examined the effect of resistance training on either strength, body composition or psychosocial outcomes.

Study Appraisal and Synthesis Methods Studies were initially critically appraised for risk of bias by the lead author, following which both co-authors critically appraised five randomly selected studies to assess reliability.

Results Randomised controlled trials and NRCTs were analysed separately from UCTs. To determine the overall intervention effect for each outcome variable for each study design group, standardised mean differences were calculated with each individual study/data set weighted by the inverse of the pooled variance. The overall intervention effect reported for RCTs and NRCTs was relative to the control group whereas the effect reported for UCTs shows an overall post-intervention effect. Subgroup analyses, which determined whether the overall intervention effect was influenced by intervention type, training volume, age, sex, risk of bias or study design (for RCT/NRCT group only), were run using the same summary measure. Typically, resistance training had very small to small effects on body composition and moderate to large effects on strength in favour of the intervention. However, the magnitude and direction of the effect of resistance training on psychological outcomes are still unclear given the limited number of studies which looked at psychosocial outcomes and the inconclusive results shown by this review. Uncontrolled trials typically showed larger intervention effects than RCTs and NRCTs; however, these results may be greatly influenced by maturational changes rather than the intervention itself.

Limitations The included studies employed a number of different exercise intervention types (e.g. resistance training, resistance plus aerobic training etc.) that ranged from 6 to 52 weeks in duration. Studies also employed a number of different methodologies to assess similar outcome measures (e.g. dual energy X-ray absorptiometry versus skinfolds to assess body composition; one-repetition maximum testing versus hand grip strength to assess strength). However, by completing subgroup analyses and using a standardised summary measure these limitations have been accounted for.

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Conclusion While the effect of resistance training on the body composition and strength of overweight and obese children and adolescents is clear, given the paucity of conclusive data more studies are needed to fully understand the effect of resistance training on the psychosocial status of this population.

1 Introduction

1.1 Rationale

In Australia approximately 20–25 % of children and adolescents are overweight or obese [1] with 10 % of children worldwide considered to be overweight [2]. There are many physical health-related problems associated with this at-risk group, such as increased prevalence of type 2 diabetes and cardiovascular disease risk [3] which have been widely reported. Less prominent are issues around psychological well-being, even though overweight and obese children and adolescents tend to be bullied and ostracised by their leaner peers, experience emotional struggles within themselves and have lower self-esteem [4].

Typically, overweight and obese children and adolescents have been encouraged to participate in aerobic activities. Compliance and adherence to such aerobic training programs may be problematical, because of the imposed physical and physiological demands and the lack of positive reinforcement these adolescents receive when obliged to perform activities at which they are less likely to be successful [5]. However in recent years the use of resistance training exercise interventions has become more popular [5–13], owing not only to its physical benefits, but also to its appeal as an exercise mode and its potential to have a positive effect on psychological well-being [14–19].

Resistance training is an exercise modality that affords overweight and obese children and adolescents the chance to outperform their leaner peers. This is because even though they carry a large fat mass, they also carry a large fat-free mass, and therefore have the potential to be stronger in absolute terms [5, 8]. So in an arena that would usually be avoided or bring about feelings of trepidation and a sense of failure, resistance training potentially provides overweight and obese children and adolescents with an outlet with which they can improve their self-efficacy and feelings of self-worth as they achieve success through participation [18].

The potential physical health-related benefits of resistance training for overweight and obese children and adolescents include increased muscle strength and endurance, aerobic fitness and bone mineral density, improved body composition and blood lipid profiles and lower blood pressure [5–10, 12, 13]. And it is these physical health-related benefits that have been widely examined and reviewed in the past [20–24]. However, resistance training also has the potential to positively affect a child's and adolescent's self-efficacy (confidence to complete a given task), physical self-concept (perception of physical ability and appearance) and global self-concept (or self-esteem) by affirming positive perceptions of an individual at the specific situational level [25, 26]. Because individuals who have low self-esteem are more likely to benefit and show improvements from exercise interventions that are designed to have a positive effect on their self-esteem [27], the effect of resistance training on the psychological well-being of overweight and obese children and adolescents needs to be evaluated in conjunction with physical health-related benefits such as body composition and strength.

1.2 Objectives

The aim of this meta-analysis was to systematically review and meta-analyse studies that have employed resistance training as part of an intervention for overweight and/or obese children and/or adolescents and have examined the effect of the intervention on their strength, body composition or psychological well-being.

2 Methods

2.1 Eligibility Criteria

Studies that met the following criteria were included in this review: (1) published in English and as a full-text manuscript or thesis; (2) not a systematic review (however the reference lists of relevant systematic reviews were searched for further studies); (3) participants were children and adolescents aged 18 years or less; (4) participants were defined as being overweight or obese using a recognised metric [e.g. body mass index (BMI) greater than the 85th percentile for age and sex]; (5) studies had to be experimental and include an intervention with a resistance training component designed to improve muscular strength and/or endurance; (6) participants were not selected on the basis of any pathology other than weight status; and (7) the study had to report strength, body composition or psychological characteristics both before and after an exercise program (for all intervention groups). Descriptive data (i.e. sample size, mean and standard deviation) had to be reported or could be derived. This review considered randomised controlled trials (RCTs), non-randomised controlled trials (NRCTs) and uncontrolled trials (UCTs).

2.2 Information Sources

Studies were located via electronic databases, in consultation with an academic librarian. Reference lists of included studies and relevant systematic reviews were also scanned, and other studies were located through contact with academic colleagues. No limits were applied for languages and the search was applied to MEDLINE (1948–January, week 4, 2013), Embase (1974–30 January 2013), Scopus (1823–30 January 2013), Web of Science (1983–January, week 4, 2013), SPORTDiscus (1949–updated monthly), CINAHL (1982–updated monthly), PsycINFO (1840–updated monthly), Cochrane library (1898–updated quarterly), Proquest Dissertations and Theses (1861–January, week 4, 2013). Each database search was run on 30 January 2013.

2.3 Search

The search strategy focussed on three semantic groups and each search was performed with search fields limited to abstract, title and keywords. Terms within each group were concatenated by the Boolean OR and were performed independently of one another before each group was concatenated by the Boolean AND. The first group identified youth (child*, or teen*, or adolescen*, or young*, or youth*, or pubes*, or pediat*, or paediat*, or boy*). The second group identified resistance training ('resistance train*', or 'resistance program*', or 'resistance exercise*', or 'resistance intervention*', or 'weight* train*', or 'weight* program*', or 'weight* exercise*', or strength*). The third group identified overweight and obesity ('obese*', or 'overweight', or 'weight status', or 'adipos*'). The asterisk is the truncation symbol.

2.4 Study Selection

The lead author carried out the eligibility assessment in an unblinded and standardised manner. Once each database search was completed and any manuscripts from colleagues were sourced, all studies were compiled into a single list with all duplicates removed. Titles and abstracts were then screened for initial eligibility and only studies that looked at resistance training and overweight and/or obese adolescents were retrieved as full text. All studies retrieved as full text were then thoroughly assessed using the complete eligibility criteria. Authors were contacted where possible to obtain missing data, clarify aspects of the study, and to obtain a full-text manuscript (this included conference abstracts where data could have been reported in full text elsewhere) or manuscripts published in English.

Studies were excluded at this point if they did not fully meet all of the inclusion criteria and/or if authors could not be contacted to clarify required aspects, a full-text manuscript could not be obtained or a copy of the manuscript published in English was not available. The reference lists of the included studies and any relevant systematic reviews, which were identified through the initial search (but were sequentially excluded), were also searched for any further studies. The same eligibility assessment process as above was then repeated until no further studies were identified.

2.5 Data Collection Process

Descriptive and quantitative data (for body composition, strength and psychological outcome variables only) were extracted and imported into an Excel spreadsheet that was designed specifically for this review. If summary data were missing (i.e. *n*, mean and SD), or if clarification of published data was required, then the study authors were contacted via email and asked to forward descriptive data tables for the required outcome variables and to clarify any inconsistencies or provide any missing information.

2.6 Data Items

The data items extracted from each of the included studies comprised descriptive data (e.g. study design, population description, sample size and intervention/control group descriptions) and outcome data that included body composition (e.g. mass, BMI, waist girth, percentage fat mass, fat mass and lean/fat-free mass), strength (e.g. one-repetition maximum for upper and lower body, hand grip strength and isometric strength) and psychological (e.g. Pediatric Quality of Life Inventory [PedsQL], self-efficacy and self-esteem) variables.

For all outcome variables only pre- and post-intervention (and control data if an RCT or NRCT) summary data were extracted for each study/data set. Several studies [14, 15, 17, 28] also reported mid-intervention or follow-up data; however, these data were not extracted for this meta-analysis.

2.7 Risk of Bias in Individual Studies

Risk of bias was assessed using two critical appraisal tools. The Critical Appraisal Skills Programme (CASP) tool for RCTs (Milton Keynes Primary Care Trust 2002) was used to appraise all included RCTs and the Lewis, Olds, Williams (LOW) critical appraisal tool [29] was used to appraise all other included studies (i.e. NRCTs and UCTs). The lead author critically appraised each of the included studies initially and following this, the two co-authors each critically appraised five separate, randomly selected studies. Intraclass correlation coefficients (ICCs) were then calculated to determine the test–retest agreement between raters.

Studies were categorised as having a high risk of bias (i.e. critical appraisal score no greater than 4) or a low risk of bias (i.e. critical appraisal score at least 5) and subgroup analysis was performed using these categories for each study design group.

2.8 Publication Bias

Publication bias was assessed by calculating Egger bias statistics [30] for a selected number of outcomes (mass, BMI, percentage body fat, lean/fat-free mass and one-repetition maximum for upper and lower body) and creating corresponding funnel plots. File drawer analysis was also run to determine the number of studies, averaging null results that must be in existence but unpublished before one would conclude that the overall published results were due to sampling bias in the reviewed studies [31].

2.9 Synthesis of Results and Summary Measures

For the purpose of this review, all studies/data sets were analysed separately according to their study design. RCTs and NRCTs were analysed independently of UCTs; however, the summary measure—the standardised mean difference (SMD)—was calculated for both research design groups. Review Manager (RevMan) software (Version 5.1. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2011) was used to calculate the SMD for each study/data set intervention group. Each individual study/data set was then weighted by the inverse of the pooled variance to calculate the overall SMD for each outcome variable for each study design group. The overall intervention effect reported for RCTs and NRCTs was relative to the control group whereas the effect reported for UCTs shows an overall post-intervention effect.

2.10 Additional Analyses

In order to determine whether the intervention effects on strength, body composition and psychological variables differed by intervention type, training volume, age, sex, risk of bias or study design (for RCT/NRCT group), subgroup analyses were run for each outcome variable for each study design group (if data were available). The subgroup analyses run were as follows:

- Intervention type: Resistance training only; Resistance training + aerobic training only; Resistance training + diet + other interventions
- Training volume: <25 h of total training; 25–50 h of total training; >50 h of total training
- Age: <12 years; ≥12 years
- Sex: Male; Female
- Risk of bias: High risk of bias (critical appraisal score ≤4); Low risk of bias (critical appraisal score ≥5)

In the subgroup analysis for age, studies/data sets were only included if they clearly fell either side of the age cut-off (12 years) based on the targeted age range for recruitment or the average age of all participants reported. In the subgroup analysis for sex, studies/data sets were only included if all participants were of the same sex or if data on males and females were analysed and reported separately. Training volume was calculated by multiplying the total duration of intervention (in weeks) by the number of sessions per week by the total duration (in minutes) for each session. The midpoint was used for studies/data sets reporting a duration range (e.g. if session duration was reported as 60–90 min, 75 min was used) and for studies that reported different session durations, the average of all sessions was used. RCTs and NRCTs were also analysed separately as another subgroup analysis for the RCT/NRCT study design group.

An overall effect (SMD) was calculated for each subgroup analysis using the same method as above. For any meta-analysis that showed significant ($p \leq 0.05$) heterogeneity, those subgroup analyses that resolved this heterogeneity were reported.

3 Results

3.1 Study Selection

After the initial database search, 3,984 studies were identified and an additional 69 studies were identified through other sources (such as personal communication with academic colleagues and searching reference lists) (see Fig. 1). Once duplicates were removed, 2,247 titles and abstracts were screened for inclusion and of those 1,990 studies were excluded. Two hundred and fifty seven studies were retrieved as full text and assessed for eligibility and of those 217 were excluded (see Fig. 1). Forty studies were therefore included in the review for quantitative synthesis. The reasons for exclusions (at the full-text level) are listed in Fig. 1.

3.2 Study Characteristics

Of the 40 included studies, 18 were RCTs [8, 12, 13, 15, 16, 18, 19, 28, 32–41], five were NRCTs [7, 9, 10, 14, 42] and 17 were UCTs [5, 6, 11, 17, 43–55]. While there were 40 individual articles that met the inclusion criteria for this review, only 35 data sets were examined.

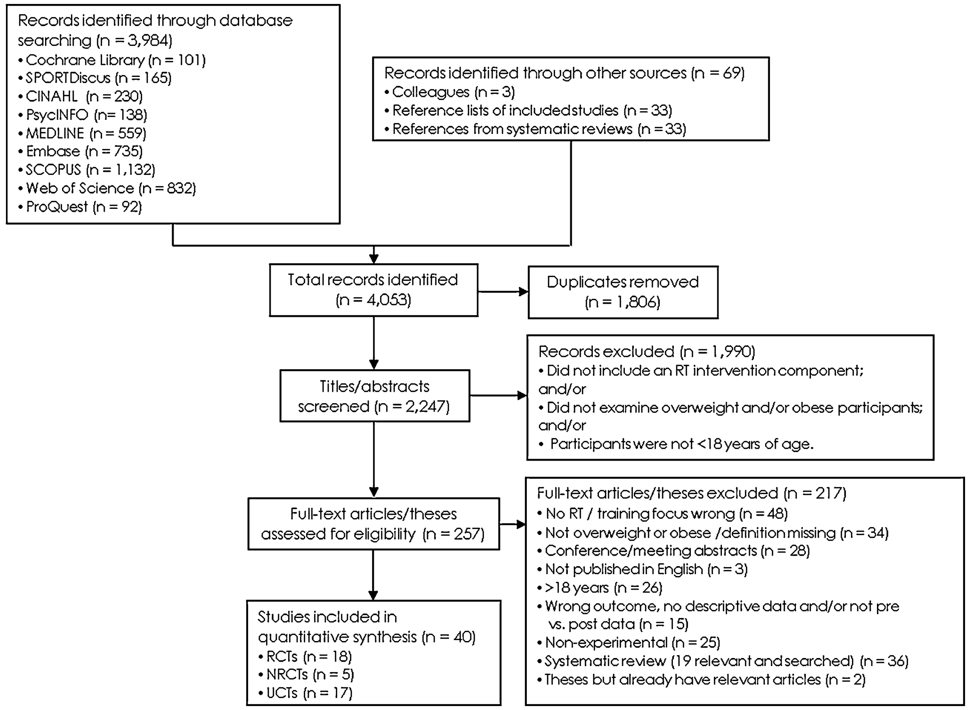

Fig. 1 PRISMA flow diagram of systematic search and included studies. *NRCT* non-randomised controlled trial, *RCT* randomised controlled trial, *RT* resistance training, *UCT* uncontrolled trial

There were four studies (two data sets) that offered an extended training period to participants after the initial training period was completed [16, 18, 19, 37]. These follow-up data were not included in this review because of self-selection bias. Table 1 describes each of the included studies/data sets and Table 2 describes each of the exercise interventions in detail.

3.3 Risk of Bias Within Studies

There was strong agreement among the authors in allocating risk of bias scores (ICC = 0.84). Most studies [83 % (15 out of 18) of the RCTs and 64 % (14 out of 22) of the NRCTs and UCTs] were categorised as having a low risk of bias (critical appraisal score at least 5).

3.4 Publication Bias

There was low evidence of publication bias. Funnel plot analysis showed no statistically significant ($p > 0.05$) risk of bias for any of the outcome variables and the number of studies required, with null results, to conclude the overall results were due to sampling bias ranged from 193 to 1,084 for RCTs/NRCTs and 43 to 4,902 for UCTs.

3.5 Synthesis of Results

The following section presents the results of the meta-analyses and subgroup analyses for each outcome variable for each study design group. Each group of outcome variables (i.e. psychological, body composition and strength) was examined separately. Firstly meta-analyses, which include all studies/data sets that have reported data for each specific outcome variable, are presented to determine the overall intervention effect. Subgroup analyses follow to determine whether the intervention effects on each outcome variable differed by intervention type, training volume, age, sex, study design (for RCT/NRCT group) or risk of bias. Results for the meta-analyses are presented using a summary forest plot (Fig. 2) and results for the subgroup analysis are summarised in text. A funnel plot relating the SMD to the inverse of variance is also shown for percentage body fat for all included study/data set groups (Fig. 3).

The summary plot (Fig. 2) was created by accumulating the overall results from each of the standard forest plots for each outcome variable. The summary plot shows each outcome (for each study design group) and the number of included study/data set groups (left side of the figure), with the overall SMD and 95 % confidence intervals (CIs) shown graphically (middle) and numerically (right). SMDs were converted so that a positive SMD reflected a favourable change in the intervention group relative to the control group for RCTs/NRCTs and a favourable change post intervention for UCTs.

Cohen's thresholds were used to describe the magnitude of the effects and also the magnitude of the difference in effects between subgroups [56]. Overall effects and differences between effects are described as very small (SMD less than 0.2), small (SMD at least 0.2 and less than 0.5),

Table 1 Description of included studies/data sets

Study design	Studies/data sets	Sex	Age range or mean ± SD (years)	Initial sample size (dropout numbers)		Overweight/ obese definition	I/C conditions	P	B	S
				Intervention group	Control group					
RCT	Davis et al. [34][a]	F	14–18	1 = 9[f] 2 = 15[f]	7[f]	BMI >85th %ile [66]	I 1 = RT + N I 2 = N + RT + AT + MI C = no conditions		●	●
	Davis et al. [33][a]	M&F	14–18	22 (5)	22 (6)	BMI >85th %ile [66]	I = RT + N+MI C = no conditions		●	●
	Davis et al. [32]	F	14–18	1 = 18 (4) 2 = 14 (2)	13 (1)	BMI >85th %ile [66]	I 1 = RT + AT I 2 = RT + AT + MI C = no conditions		●	●
	de Mello et al. [28]	M&F	16.7 ± 1.47	21 (6)	22 (7)	BMI >95th %ile [66]	I = RT + AT + therapy C = AT		●	
	de Piano et al. [38][e]	M&F	16.5 ± 1.4	15 (0)	15 (0)	BMI >95th %ile [66]	I = RT + AT + N+ Psych C = AT + N+ Psych		●	
	Kim et al. [35]	M	11	12 (4)	12 (3)	BMI >85th %ile [67]	I = RT + AT C = no conditions		●	
	Kim (thesis) [12][b]	M	12–18[j]	13 (0)	7 (0)	BMI >95th %ile [66]	I = RT C = no conditions		●	●
	Lee et al. [13][b,c]	M	12–18[j]	15 (0)	13 (2)	BMI ≥95th %ile [66]	I = RT C = no conditions		●	●
	Lison et al. [39]	M&F	6–16	1 = 45 (13) 2 = 41 (9)	24 (0)	BMI >85th %ile [68]	I 1 = RT + AT + D (clinic) I 2 = RT + AT + D (home) C = no conditions		●	
	Park et al. [40]	M&F	12–13	15 (0)	14 (0)	BMI ≥85th %ile [69]	I = RT + AT C = no conditions		●	
	Shaibi et al. [8]	M	15.1 ± 0.5	14 (3)	14 (3)	BMI >85th %ile [66]	I = RT C = no conditions		●	●
	Shalitin et al. [15]	M&F	6–11	1 = 52 (14) 2 = 55 (9)	55 (19)	BMI >95th %ile	I 1 = RT + D I 2 = RT + AT + D C = D	●	●	
	Suh et al. [41][b]	M&F	13.1 ± 0.3(I) and 13.1 ± 0.6(C)	10 (0)	10 (0)	BMI 85th %ile [69]	I = RT + D C = D		●	
	Sung et al. [16]; Yu et al. [18, 19]	M&F	8–11	41 (0)	41 (0)	Mass >120 % median mass for height [70]	I = RT + AT + D C = D	●	●	●
	Wong et al. [36]	M	13–14	12 (0)	12 (0)	BMI ≥25 kg/m^2 [66]	I = RT + AT + Sports C = no conditions		●	
	Woo et al. [37]	M&F	9–12	41 (19)	41 (0)	BMI ≥21 kg/m^2 [66]	I = RT + AT + D C = D		●	
NRCT	Dove (thesis) [14]	F	13.06 ± 1.1(I) and 13.05 ± 1.0(C)	22 (0)	20 (0)	BMI >85th %ile	I = RT + AT + D+ BT C = no conditions	●	●	●
	Lee et al. [42][b]	M&F	12–14	20[f]	18[f]	BMI >95th %ile	I = RT + AT C = no conditions		●	●
	Naylor et al. [7][h]	M&F	12.2 ± 0.4(I) and 13.6 ± 0.7(C)	13 (0)	10 (0)	BMI >30 kg/m^2 [68]	I = RT C = no conditions		●	●
	Treuth et al. [9, 10][h]	F	7–10	12 (1)	11 (0)	BMI >95th %ile [71]	I = RT C = no conditions[g]		●	●

Table 1 continued

Study design	Studies/data sets	Sex	Age range or mean ± SD (years)	Initial sample size (dropout numbers)		Overweight/ obese definition	I/C conditions	P	B	S
				Intervention group	Control group					
UCT	Bell et al. [46]	M&F	9–16	14 (0)	N/A	BMI >95th %ile [68]	I = RT + AT		●	
	Evans et al. [47]	M&F	13.4 ± 1.8	168 (104)	N/A	BMI >95th %ile [66]	I = RT + AT + N+BT		●	
	Farris et al. [43]	M&F	6–12	51 (26)	N/A	BMI ≥95th %ile [72]	I = RT + AT		●	
	Foschini et al. [48]	M&F	16.5 ± 1.74	1 = 16 (0) 2 = 16 (0)	N/A	BMI >95th %ile [66]	I 1 = DUP RT + AT + BT I 2 = LP RT + AT + BT			
	Hardy et al. [44][d]	M&F	16.3 ± 1.1	9[f]	N/A	BMI >85th %ile [66]	I = RT + AT + N/Ex		●	
	Lau et al. [6]	M&F	12.45 ± 1.77	18(0)	N/A	BMI >obese [58]	I = RT		●	●
	Lazzer et al. [49–51][i]	M&F	12–16	27 (1)	N/A	BMI >97th %ile [73]	I = RT + AT + D+N		●	
	McGuigan et al. [5]	M&F	7–12	63 (15)	N/A	BMI >85th %ile [74]	I = RT		●	●
	Rynders et al. [45]	M&F	14.3 ± 2.4	1&2 = 37 (21)	N/A	BMI >95th %ile[k]	I 1 = RT + AT + D I 2 = RT + AT + D+Met		●	
	Sothern et al. [54]	M&F	7–17	56 (21)	N/A	Mass ≥130 % IBW [71]	I = RT + AT + D+N + BT		●	
	Sothern et al. [52]	M&F	7–17	87 (0)	N/A	Mass ≥120 % IBW [71]	I = RT + AT + D+N + BT		●	
	Sothern et al. [53]	M&F	7–12	15 (0)	N/A	Mass ≥120 % IBW [71]	I = RT + AT + D+N + BT		●	
	van der Heijden et al. [11]	M&F	15.5 ± 0.5	12 (0)	N/A	BMI >95th %ile [66]	I = RT		●	
	Wickham et al. [55]	M&F	11–18	165 (108)	N/A	BMI ≥95th %ile [75]	I = RT + AT + N+BT		●	
	Wilson et al. [17]	M&F	14.6[l]	52 (2)	N/A	BMI >95th %ile	I = RT + AT + BT	●	●	●

%ile percentile, *AT* aerobic training, *B* body composition outcomes measured, *BMI* body mass index, *BT* behaviour therapy, *C* control group, *D* diet, *DUP* daily undulating periodisation, *Ex* exercise education, *F* female, *I* intervention group, *IBW* ideal body weight, *LP* linear periodisation, *M* male, *Met* metformin, *MI* motivational interviewing, *N* nutrition education, *NRCT* non-randomised controlled trial, *P* psychological outcomes measured, *Psych* psychological support, *RCT* randomised controlled trial, *RT* resistance training, *S* strength outcomes measured, *SD* standard deviation, *UCT* uncontrolled trial

[a] Study includes additional nutrition education (only) intervention group but not reported here as not relevant to the review

[b] Study includes an AT-only group but not reported here as not relevant to review (study also has a no condition control group)

[c] Study also included a diet regime but not reported here as it was considered a maintenance program which had the purpose of allowing the true effect of the exercise intervention to be examined

[d] Study includes a lean intervention group but not reported here as not relevant to review

[e] Study includes an intervention arm with participants diagnosed with non-alcoholic fatty liver disease but not reported on in this review as considered atypical

[f] Dropout data not reported for each group only total sample

[g] Control group not overweight or obese (i.e. BMI <95th percentile)

[h] Study/data set does not report control data for all outcome variables; for those variables study/data set combined with uncontrolled trials

[i] Male and female data reported separately

[j] The age range of participants includes 18; however, the mean age falls well below 18 years for all intervention/control groups

[k] National Institute of Health (2000 data) published BMI percentile guidelines used to classify overweight and obese

[l] No SD reported

Table 2 Description of each exercise intervention for included studies/data sets

Studies/data sets	Training duration (weeks)	Sessions/ week	Session duration (min)	Training volume (h)	Intensity/sets and repetitions	Exercises/description
Davis et al. [34]	16	2	60	32	1: RT = 62–97 % baseline 1RM, 1–3 sets × 8–15 reps 2: RT = low to heavy weight, 8–14 reps; AT = 70–85 % max HR	1: RT = compound and isolated UB LB exercises alternating each day 2: Circuit format = 2 min RT + 2 min AT, 30 min each
Davis et al. [33]; Shaibi et al. [8]	16	2	60	32	RT = 62–97 % baseline 1RM, 1–3 sets × 8–15 reps	RT = compound and isolated UB LB exercises alternating each day
Davis et al. [32]	16	2	60–90	40	RT = low to heavy weight, 8–14 reps; AT = 70–85 % max HR	Circuit format = 2 min RT + 2 min AT, 30 min each
de Mello et al. [28]	52	3	60	156	I: RT = 3 sets × 6–20 reps; AT = HR of the VT (±4 bpm) C: AT = 50–70 % VO_2max	I: RT = 10 × compound and isolated UB and LB exercises, 30 min; AT = treadmill running, 30 min C: AT = cycling and treadmill, 60 min
de Piano et al. [38]	52	3	30(AT)/ 30(RT)	156	I: RT = 3 sets × 6–20 reps; AT = HR of the VT (±4 bpm) C: AT = 50–70 % VT	I: RT = targeted main muscle groups, 30 min; AT = treadmill running, 30 min C: AT = cycling and treadmill, 60 min
Kim et al. [35]	12	4 (2 × AT/ 2 × RT)	30(AT)/ 50(RT)	32	RT = 70 % 1RM and then increased when could perform 20 reps; AT = 55–75 % max HR	RT = 9 × compound and isolated UB and LB exercises, rubber bands used; AT = walking
Kim [12]	12	3	30–60	36	RT = 50 to >60 % baseline 1RM, 1–2 sets × 12 reps	RT = 10 × compound and isolated UB and LB exercises
Lee et al. [13]	12	3	60	36	RT = 60 % baseline 1RM–fatigue, 1–2 sets × 8–12 reps	RT = 10 × compound and isolated UB and LB exercises.
Lison et al. [39]	26	3 minimum	35(AT)/ 20(RT)	78	RT = low load and high reps (15–30) AT = not stated	Circuit format = body weight and dumbbell exercises targeting major muscle groups (RT) and sports/games/ brisk walking (AT)
Park et al. [40]	12	3	80	48	RT = 60 % 1RM, 2 sets × 8–12 reps AT = 50–70 % HRR	RT = 7 dynamic compound and isolated UB and LB exercises AT = treadmill walking and/or running
Shalitin et al. [15]	12	3	90	54	Not stated	RT = sit-ups, hand lifting of small weights and ball exercises, 45 min; AT = team sports and running games, 45 min
Suh et al. [41]	12	3	60[a]	36	RT = 60 % 1RM, 2–3 sets × 10–12 reps	RT = 10 × compound UB and LB exercises targeting major muscle groups
Sung et al. [16]; Yu et al. [18, 19]	6	3	75	22.5	RT = 75–100 % 10RM, 1 set × 20 reps; AT = 60–70 % max HR	RT = 9 × large muscle group exercises, 30 min; AT = treadmill, cycling, stepper, dance and agility exercises, 20 min (Circuit format)
Wong et al. [36]	12	2	45–60	21	RT = 1–3 sets × 8–25 reps; AT and Sports = 50–85% HR max	RT = 4–7 × compound and isolated UB and LB exercises—body weight and medicine balls; AT = not stated (circuit format)
Woo et al. [37]	6	2	75	15	RT = not stated; AT = 60–70 % max HR	RT = 30 min; AT = dance, 10 min (Circuit format)
Dove [14]	10	4 (3 × RT/ 1 × AT)	30	20	Not stated	RT = 13 hydraulic machines AT = not stated (circuit format)
Lee et al. [42]	10	3	60	30	RT = 70–80 % maximum strength, 30 s of each exercise AT = 60–80 % VO_2max	RT Circuit format = 8–10 × body weight exercises AT = sports and games

Table 2 continued

Studies/data sets	Training duration (weeks)	Sessions/ week	Session duration (min)	Training volume (h)	Intensity/sets and repetitions	Exercises/description
Naylor et al. [7]	8	3	60	24	RT = 75–90 % max VC, 2 sets × 8 reps	10 × weight-stack machines (circuit format)
Treuth et al. [9, 10]	22	3	20	22	RT = 50–70 % 1RM, 2 sets × 12–15	7 × compound and isolated UB and LB exercises (circuit format)
Bell et al. [46]	8	3	60	24	RT = 55–65 % of max VC; AT = 65–85 % max HR	RT = 10 weight-stack machines AT = stationary cycle (circuit format)
Evans et al. [47]; Wickham et al. [55]	26	1@clinic/ 2@home	60	78	RT = 2–3 sets × 12–15 reps; AT ≥150 bpm (>70 % max HR)	RT = 10 × major muscle group exercises, 30 min; AT = treadmill or cycling, 30 min
Farris et al. [43]	12	2	60	24	RT and AT = working at a perceived effort of 6–7 out of 10	RT = machines and body weight exercises AT = jogging, walking, jumping rope
Foschini et al. [48]	14	3	60	42	RT = 3 sets × 6–20RM, number of reps changes daily or every 4–6 weeks; AT = HR of the VT (±4 bpm)	RT = 10 × compound and isolated UB and LB exercises; AT = treadmill running, 30 min
Hardy et al. [44]	13	2–4	45–60	39.5	Not stated	Not stated
Lau et al. [6]	6	3	60	18	RT = 70–85 % 1RM, 1–3 sets × 5–8 reps	10 × compound and isolated UB and LB exercises
Lazzer et al. [49–51]	38	2	40	50.7	RT = 3 sets × 20 reps; AT = 55–60 % VO_2 max	RT = 6 × compound and isolated UB and LB exercises; AT = cycling, treadmill, rowing, stepper
McGuigan et al. [5]	8	3	60[a]	24	RT = 3 sets × 3–15 reps, number of reps changes each day	RT = compound and isolated UB and LB exercises and explosive power exercises
Rynders et al. [45]	26	3	30–60	58.5	Not stated	RT = weight stack machines AT = treadmill, cycle and rower ergometer
Sothern et al. [52–54]	52	1@clinic/ 1@home	30–45/ 20–30	54.2	RT = 60 % 1RM, 1 set × 8–12 reps; AT = 45–55 % VO_2 max	RT = 6–12 compound and isolated UB and LB exercises using hand and ankle weights; AT = different exercise options
van der Heijden et al. [11]	12	2	60	24	RT = 50–85 % 3RM, 2–3 sets × 8–20 reps	18 × compound and isolated UB and LB exercise, gym machines, hand-held weights and physioball used
Wilson et al. [17]	12	1–3	60	27	RT = 1–2 sets × 10–15 reps AT = 40–79 % HRR	RT = 12 × compound and isolated UB and LB exercises AT = treadmill and cycle, stepper and rower ergometers

Many studies/data sets include additional intervention conditions such as diet, nutritional education or behaviour therapy (see Table 1); however, they are not described here

AT aerobic training, *bpm* beats per minute, *C* control group, *h* hour, *HR* heart rate, *HRR* heart rate reserve, *I* intervention group, *LB* lower body, *min* minutes, *reps* repetitions, *RM* repetition maximum, *RT* resistance training, *UB* upper body, *VC* voluntary contraction, *VO_2 max* maximal oxygen uptake, *VT* ventilatory threshold

[a] Duration of each session not specifically stated but detailed outline of each session is reported and therefore 60 min is an approximated session duration

moderate (SMD at least 0.5 and less than 0.8) and large (SMD at least 0.8). There were two NRCTs [7, 9] that did not present control data for all outcome variables. Intervention data were subsequently included in the UCTs meta-analysis for outcome variables for which no control data were reported.

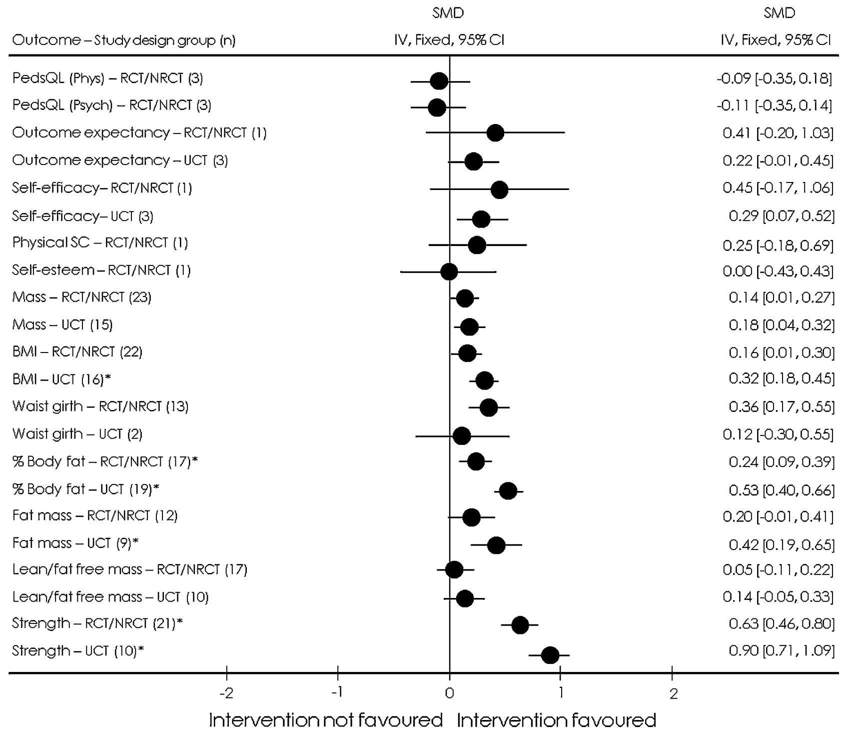

Fig. 2 Summary of all body composition, strength and psychological meta-analyses. *BMI* body mass index, *CI* confidence interval, *IV* inverse variance, *n* number of study/data set groups included in each meta-analysis, *NRCT* non-randomised controlled trial, *Phys* physical health, *Psych* psychosocial health, *RCT* randomised controlled trial, *QL* quality of life, *SC* self-concept, *SMD* standardised mean difference, *UCT* uncontrolled trial. *Significant heterogeneity shown for that outcome variable

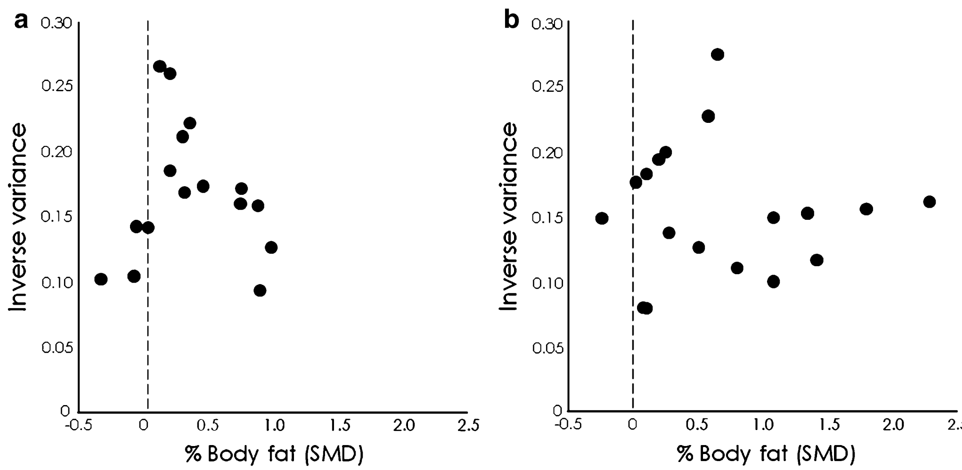

Fig. 3 Funnel plot for percentage body fat SMD and inverse variance for all studies/data set groups: **a** randomised and non-randomised controlled trials; **b** uncontrolled trials. *SMD* standardised mean difference

3.5.1 Psychological Outcomes

To summarise the main results, very small to small but non-significant (with the exception of self-efficacy for UCTs) intervention effects for all outcomes variables were apparent (Fig. 2). Subgroup analyses showed that training volume, age and study design typically have a small influence on the overall intervention effects (for PedsQL, physical health) with high training volumes, younger children/adolescents and RCTs yielding the largest effects. However, results for each subgroup were still in favour of the control group. As a result of the small number of studies examining the other psychological outcomes, no other subgroup comparisons could be made.

Overall, the effect of resistance training on psychosocial variables is unclear as very small to small and non-significant effects were shown in favour of both the intervention and control group, with the overall effects differing by training volume, age and study design.

3.5.2 Body Composition

Body composition was assessed using two common methodologies by the included studies: anthropometric measures such as girths and skinfolds and dual energy X-ray absorptiometry. In general, RCTs and NRCTs showed very small to small intervention effects on body composition whereas UCTs showed very small to moderate improvements (Fig. 2).

When examining RCTs and NRCTs there were very small to small improvements in all body composition outcomes relative to controls (SMD range 0.05–0.36), all of which were statistically significant except for fat mass and lean/fat-free mass (Fig. 2). In comparison, UCTs yielded generally more favourable effect sizes: small to moderate reductions in mass (SMD $\pm$ 95 % CI 0.18 $\pm$ 0.14), BMI (SMD 0.32 $\pm$ 0.14), percentage body fat (SMD 0.53 $\pm$ 0.13) and fat mass (SMD 0.42 $\pm$ 0.23) (Fig. 2).

Further examination of both study designs shows significant heterogeneity for BMI (UCTs), percentage body fat (RCTs/NRCTs and UCTs) and fat mass (UCTs) (Fig. 2). There was no significant heterogeneity when the following subgroup analyses were performed: intervention types (BMI, percentage body fat and fat mass), age groups [BMI and fat mass (less than 12 years)] and training volume [BMI (less than 25 and 25–50 h), percentage body fat (less than 25 h) and fat mass (all subgroups).

Following subgroup analyses, for the RCT/NRCT group, intervention type had a very small to small influence on the overall intervention effect with those interventions with an aerobic training component showing the largest effects [for percentage body fat (versus resistance training only) and fat mass (versus interventions with a dietary component)]. Training volume had a small to large influence on intervention effects with moderate (greater than 25 to less than 50 h) to high (at least 50 h) training volumes typically showing the largest effects (for BMI, waist girth, percentage body fat and fat mass). Age had a very small to small influence on intervention effects with older children/adolescents (at least 12 years) typically showing the largest effects (for mass, BMI, waist girth, percentage body fat and fat mass). Sex, study design (RCT versus NRCT) and risk of bias had a very small to moderate influence on the overall intervention effect with males (for mass, BMI, percentage body fat and fat mass), RCTs (for BMI) and high risk of bias studies (for percentage body fat and fat mass) typically showing the largest effects.

In contrast, for the UCT group, intervention type had a small to large influence on intervention effects with interventions including a dietary component (for mass, BMI, percentage body fat and fat mass) and interventions with an aerobic training component (for BMI and waist girth) typically showing the largest effects. Training volume had a very small to large influence on overall intervention effects with moderate to high training volumes typically showing the largest effects (for mass, BMI, percentage body fat and fat mass). Sex generally had a moderate to large influence, and age a very small to moderate influence on intervention effects with interventions involving males (for BMI, percentage body fat and fat mass) and older children/adolescents (for mass, waist girth, percentage body fat, fat mass and lean/fat-free mass) typically showing the largest effects. Risk of bias had a very small to moderate influence on intervention effects with low-risk studies typically showing the largest effects (for waist girth and fat mass).

In summary, resistance training interventions typically produced very small to small changes in body composition. Subgroup analyses typically resulted in small influences on overall intervention effects and the differences between subgroups were generally small. This was particularly the case for controlled trials versus uncontrolled trials.

3.5.3 Strength

Strength was assessed using a number of methodologies including one-repetition maxima for upper and lower body, isometric knee extension, and hand grip strength. Overall, moderate to large positive intervention effects were shown for both meta-analyses (Fig. 2) and for all subgroup analyses with UCTs again showing larger effects than the RCTs/NRCTs group.

When examining RCTS/NRCTs, intervention type and sex had a small to large influence on the overall intervention effects with resistance training-only interventions and those involving males typically yielding more favourable results. Training volume, age, study design and risk of bias had a small to moderate influence on the overall intervention effects with moderate training volumes, older children/adolescents, RCTs and studies with a low risk of bias all typically showing the largest effects. In contrast, the only substantial differences that were calculated between subgroups for UCTs were for training volume, age and risk of bias, with moderate training volumes, younger children/adolescents and high risk of bias studies generally showing the largest effects.

In summary, resistance training typically results in moderate to large improvements in strength, with UCTs typically showing larger improvements. The overall intervention effects were larger for RCTs than for NRCTs, for resistance training-only interventions with a moderate training volume, and for studies using males.

4 Discussion

4.1 Summary of Evidence

This systematic review shows that interventions with a resistance training component have very small to small effects on body composition and moderate to large effects on strength gains in overweight and obese children and adolescents. The magnitude and direction of the psychological effect of resistance training for overweight and obese children and adolescents are unclear, given that none of the reviewed studies examining psychological effects used a resistance training-only intervention. Uncontrolled trials generally showed larger intervention effects than RCTs and NRCTs; however, without a control group for comparison, the results from UCTs should be treated with caution as the observed changes could be heavily influenced by maturational changes rather than as a result of the intervention itself.

This review has shown for RCTs/NRCTs that resistance training-only interventions typically showed similar effects for body composition outcomes compared to those studies that used a resistance plus aerobic training intervention or those that included a dietary component. In contrast, UCTs that used a resistance training-only intervention typically showed smaller effects (small to large differences) in comparison to the other intervention types. For strength, RCTs/NRCTs that used resistance training only typically showed larger effects (moderate to large differences) in comparison to those studies that included an aerobic training or dietary component. Similar comparisons among different intervention types could not be made for UCTs as all of the reviewed studies used resistance training-only interventions.

Although this review examined the influence of different intervention types on the overall intervention effects of resistance training, it is also important to compare the observed effects of resistance training to other exercise modalities such as aerobic training. To assess the differences in effects between different exercise modalities, the results from this review were compared to those of seven studies [four RCTs (two compared effects to another intervention and therefore were treated as UCTs as they did not have a true control comparison group) [57, 58], one NRCT and two UCTs] that examined the effects of aerobic training on body composition, strength and psychological outcomes for overweight and/or obese adolescents and that were located independently of this review [57–63]. These studies examined the effects of aerobic training on 240 overweight and obese adolescents from seven different countries, who trained 30–90 min per session, 2–4 times per week for 6–14 weeks at a moderate to high intensity level.

Consider first the results of the comparison of effects on body composition outcomes. Controlled studies [57, 58, 60] showed that aerobic training typically produced very small to small effects (i.e. very small to small differences between intervention and control groups) for percentage body fat and fat mass with only the effects for percentage body fat in favour of the intervention group. The uncontrolled studies [57, 58, 61, 63] showed that aerobic training typically produced very small to small declines in percentage body fat and fat mass, with none of the effects reported as statistically significant. Secondly, one study [58], which did not have a true control group for comparison, reported that aerobic training (high intensity intervals performed twice a week for 12 weeks) produced small and non-statistically significant improvements in maximal leg strength for overweight and/or obese adolescents. Thirdly, one RCT [59] reported that aerobic training (intermittent aerobic exercises at a moderate intensity, for 14 weeks) produced substantial improvements (relative to controls and/or an exercise placebo group) of 5.3–6.5 % and 10.5–12.3 % in physical and global self-worth for obese adolescents.

While these results may not be typical of all aerobic training studies that have assessed changes in body composition, strength and psychological outcomes in this population, they nonetheless provide a benchmark and suggest that resistance training has similar effects on body composition and more favourable effects on strength. However, more studies examining the effects of resistance training on psychological outcomes are needed to make a better comparison with aerobic training.

When examining other systematic reviews and meta-analyses there are quite a few consistent trends when looking at the effects of exercise training on body composition and strength. Session duration and program length were significantly associated with changes in body composition with longer-lasting sessions and programs the best predictors of positive body composition changes [64, 65]. The same two meta-analyses also found that aerobic plus resistance training interventions produced greater improvements in body composition in contrast to interventions that only employed one mode of exercise [64, 65]. A meta-analysis by Behringer [21], which examined the effects of resistance training-only interventions on maximal strength, reported similar findings in regards to session duration and program length with longer-lasting sessions and programs eliciting the largest effects. Age was also found to be a significant predictor for changes in strength with older children/adolescents showing the largest effects; however, there were no significant differences between males and females [21]. This review also reported similar results with interventions involving higher training volumes, older children/adolescents and males typically yielding the largest effects for body composition and strength outcomes for the subgroup analyses.

4.2 Strengths and Limitations

There were a number of strengths to this systematic review. Firstly, using a strict set of inclusion/exclusion criteria, this study synthesised the results of 35 studies/data sets that measured the resistance training effects (using various intervention types that included a resistance training component) on body composition, strength and psychological outcomes in 1,505 overweight and obese children and adolescents from 10 countries. Secondly, it analysed data from RCTs/NRCTs and UCTs separately to assess the differential effects of study design. Thirdly, numerous subgroup analyses were performed to examine the impact of different intervention types, training volumes, age, sex, study design and risk of bias on the main findings. Finally, there should be strong confidence in the main findings (at least for the resistance training effects on body composition and strength) given that the critical appraisal process revealed that most of the reviewed studies (73 % or 29 of 40) were classified as having a low risk of bias, with those classified as high risk typically (73 % or 8 of 11) employing a UCT research design.

As with any study, there are limitations that need to be considered when interpreting the results. Firstly, the included studies employed a number of different exercise intervention types (e.g. resistance training, resistance plus aerobic training) that ranged from 6 to 52 weeks in duration. Despite this methodological variability, the results of the subgroup analyses generally showed similar outcome effects across different intervention types and training volumes.

Secondly, 20 % (or 7 of 35) of the included studies/data sets used a control group that was not considered to be a 'true' control group (i.e. the control group also received some type of intervention such as restricted diet or aerobic training) [15, 16, 18, 19, 28, 37, 38, 41] or was not representative of the members of the intervention group (i.e. not overweight and/or obese) [9, 10]. Despite this, further examination of the reviewed studies showed that the differences in intervention effects between the studies with and without a 'true' control group were typically very small to small.

Thirdly, the data for individual outcome measures were pooled across studies that did not always use the same test measures or protocols, or did not always use criterion test measures (e.g. measures of fat mass included indirect measures such as skinfolds and direct, criterion measures such as dual energy X-ray absorptiometry). While it is acknowledged that it is not ideal to combine data from test measures that differ in validity, it is important to understand that data were combined on the basis of the underlying constructs in order to get an estimate of the overall effects and to minimise the number of comparisons made. The reporting of intervention effects as standardised mean differences meant that differences in test measures and metrics were catered for and an estimate of the overall 'construct' effects could be made.

Lastly, while it would have been ideal to include training intensity as a subgroup this was not possible given the lack of information provided by a number of studies regarding this aspect of the prescribed training programs.

5 Conclusions

This systematic review showed that resistance training in overweight and obese children and adolescents appears to generally have very small to small effects on body composition and moderate to large effects on strength, yet the effects on psychosocial status are at present unclear. Whilst UCTs typically showed larger effects than RCTs, it is probable that the resistance training effects from UCTs were overestimated because these trials do not control for changes in maturation, and therefore, more confidence should be placed on the results from the RCTs. Given the paucity of data, it is recommended that more studies need to be conducted that examine the effects of resistance training on the psychological well-being of overweight and obese children and adolescents.

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