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How hard should you train? A meta-analysis of studies comparing body composition changes between interval training and moderate intensity continuous training

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ABSTRACT

Objectives: To conduct a systematic review and multilevel meta-analysis of the current literature as to the effects of interval training (IT) vs moderate intensity continuous training (MICT) on measures of body composition, both on a whole-body and regional level. **Design:** Systematic review and meta-analysis. **Data sources:** English-language searches of PubMed/MEDLINE, Scopus, and CINAHL conducted in accordance with PRISMA guidelines. **Eligibility criteria for selecting studies:** a) randomized controlled trials that directly compared IT vs MICT body composition using a validated measure in healthy children and adults; b) training was carried out a minimum of once per week for at least four weeks; c) published in a peer-reviewed English language journal or on a pre-print server. **Results:** The main model for fat mass effects revealed a trivial standardized point estimate with high precision for the interval estimate, with negligible heterogeneity. The main model for lean mass effects revealed a trivial standardized point estimate with high precision for the interval estimate, with negligible heterogeneity. The GRADE summary of findings suggested high certainty for both main model effects. In comparison to non-intervention control groups, the IT conditions resulted in small reductions in fat mass and trivial increases in lean mass. The MICT conditions also produced small reductions in fat mass, and trivial increases in lean mass. Analysis of regional fat loss revealed trivial between group comparative treatment effects for upper body, lower body and trunk regions with minimal differences between regions. **Conclusion:** Our findings provide compelling

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evidence that the intensity of effort during endurance exercise has minimal influence on longitudinal changes in fat mass and lean mass.

Trial registration number: The study was preregistered on the Open Science Framework (https://osf.io/dq784).

KEYWORDS: intensity of effort; fat loss; fat mass; body fat; lean mass

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Introduction

The relative components of fat mass and fat-free mass in the body, collectively termed body composition, has important implications for human health. Excessive levels of body fat show a high correlation with a panoply of disease states, including cardiovascular diseases, metabolic disorders, certain cancers, osteoarthritis, and respiratory conditions (1). Alternatively, low levels of fat-free mass are associated with a loss of strength, functional capacity, and reduced bone mineral density (2-4), impairing both the quality and quantity of life (1). There is an interaction between these two components, whereby the combination of low levels of lean mass and high levels of body fat potentiate each other, maximizing their impact on disability, morbidity, and mortality (5).

Exercise is commonly recommended as an intervention to improve body composition (6, 7). Interventional strategies often employed for this purpose include:

1. Moderate intensity continuous training (MICT), herein operationally defined as moderate intensity of effort exercise (<80% peak heart rate or aerobic capacity) performed in a longer (relative to interval training bouts) single bout.
2. Interval training (IT), herein operationally defined as exercise performed in multiple shorter (relative to continuous training) bouts interspersed with recovery periods either at lower intensities of effort, or as complete rest.

IT is often subclassified into high intensity interval training (HIIT), herein operationally defined as high intensity of effort exercise (>80% peak heart rate or aerobic capacity) performed in multiple shorter bouts interspersed with recovery periods either at lower intensities of effort or as complete rest, and sprint interval training (SIT), herein operationally defined as maximal intensity of effort exercise ('all out' sprint) performed in multiple shorter bouts interspersed with recovery periods either at lower intensities of effort or as complete rest.

Although both MICT and IT show efficacy in improving body composition, controversy exists as to whether one strategy is superior to the other for this purpose. In an attempt to address this question, Viana et al. (8) conducted a meta-analysis on the effects of interval training vs MICT on body fat. Results showed that IT produced a 28.5% greater reduction in fat mass than MICT. However, the paper was criticized for various methodological issues (9), ultimately leading to its retraction. More recently, Sultana et al. (10) carried out a meta-analysis that included a comparison of IT vs MICT. The analysis did not find a benefit to low-volume IT on measures of body composition when compared with MICT. However, they limited their analysis to only single measures per study of the constructs of interest (i.e., total body fat mass, body fat percentage, and lean body mass), whereas many studies often report several measures (e.g., regional measures). Further, although several studies have also compared the effects of IT and MICT in younger populations, they limited the analysis to adults. Also, it is not clear form their analysis what pre-post test correlations were imputed and used for effect size calculations. The magnitude of pre-post test correlations used in calculation of pre-post control group design effect sizes using pooled baseline standard deviations can impact the heterogeneity determined in the meta-analysis (11). Thus, although the standardized point estimates of Sultana et al. (10) models generally suggested little difference between conditions, the accompanying interval estimates for most outcomes included small effects in favor of either IT or MICT. Further, their models had essentially no heterogeneity, although this may be a result of imputation of pre-post correlations that were relatively low. Application of multilevel meta-analytic models with robust variance estimation to handle multiple effects per study might yield greater precision of estimates (12), and thus help to confirm whether small differences do in fact exist, and if so, in which direction. Additionally, extraction of information to permit calculation of pre-post test correlations within groups (i.e., see here) would allow for a better estimate of the population pre-post test correlations and may reveal heterogeneity not identified in previous analyses. Lastly, although Sultana et al. (10) explored 'within-condition' effects for IT in studies that included a non-exercising control condition, they did not similarly explore this outcome for MICT training.

It also has been speculated that specific exercise-induced effects might occur for hypertrophy and regional fat mass. Endurance exercise may have beneficial effects on muscle hypertrophy, similar to that of resistance training (13), and some researchers highlight that IT, in particular, may produce a potent anabolic stimulus (14). Further, it has been suggested that IT may be more effective than MICT for abdominal fat mass reduction (15). However, to our knowledge, no previous review has pooled data from research that directly compares changes in lean mass between IT and MICT, nor specifically examined regional effects on changes in fat mass.

Lastly, although prior meta-analyses have considered between-conditions comparison of mean intervention effects (10), whether or not differences in the variance of treatment responses are present has been relatively less explored. A recent meta-analysis of aerobic exercise in overweight and obese children and adolescents found no evidence of 'true' inter-individual response variation in fat loss (16). However, numerous studies have purported that there may be inter-individual response variation to IT and MICT for a range of outcomes (17-19), and indeed it has been argued that such variation may mask differences between IT and MICT for fat loss (20). Thus, we also sought to examine whether there is evidence of 'true' inter-individual response variation for body composition outcomes for both IT and MICT (21, 22).

Given the gaps in the current literature, the purpose of this paper was to conduct a systematic review and multilevel meta-analysis of the current literature as to the effects of IT vs MICT on measures of body composition, both on a whole-body and regional level. Secondarily, we sought to determine if intensity of effort influences exercise adherence and/or adverse events, as well as whether inter-individual response to IT and MICT influences changes in body composition.

Methods

This systematic review was conducted in accordance with the guidelines of the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) (23). The study was preregistered on the Open Science Framework (https://osf.io/dq784) where the detailed prespecified methodological protocol can be viewed.

Inclusion/Exclusion Criteria

We included studies that met the following criteria: a) randomized controlled trials (both within- and between-group-designs) that directly compared IT vs MICT (both with and without adjuvant dietary interventions) for body composition using a validated measure (DXA, BodPod, hydrostatic weighing, BIA, skinfold, ultrasound, magnetic resonance imaging, and computerized tomography) in healthy children and adults; b) training was carried out a minimum of once per week for at least four weeks; c) published in a peer-reviewed English language journal or on a pre-print server. We excluded studies that employed: a) participants with co-morbidities that might impair aerobic capacity (respiratory conditions, musculoskeletal injury); b) an unbalanced resistance training component (e.g., one group performs resistance training whereas the other does not).

Search Strategy

We carried out a comprehensive search of the PubMed/MEDLINE, Scopus, and CINAHL databases using the following Boolean string: (interval training OR intermittent training OR high intensity OR sprint interval training OR aerobic interval training OR HIIT OR HIIE OR high intensity interval training OR high-intensity interval training OR high intensity interval exercise OR high intensity intermittent exercise OR high-intensity intermittent exercise OR high intensity intermittent training OR high-intensity intermittent training) AND (continuous training OR moderate-intensity continuous exercise OR moderate intensity continuous exercise OR moderate-intensity continuous training OR moderate intensity continuous training OR endurance training) AND (body fat OR adiposity OR body composition OR abdominal fat OR visceral fat OR adipose tissue OR fat mass OR fat-free mass OR lean body mass OR lean mass OR muscle mass). Moreover, we screened the reference lists of articles retrieved to uncover any additional studies that might meet inclusion criteria as described by Greenhalgh and Peacock (24). The search was finalized on March 6th, 2021; Figure 1 illustrates a flow chart of the search process.

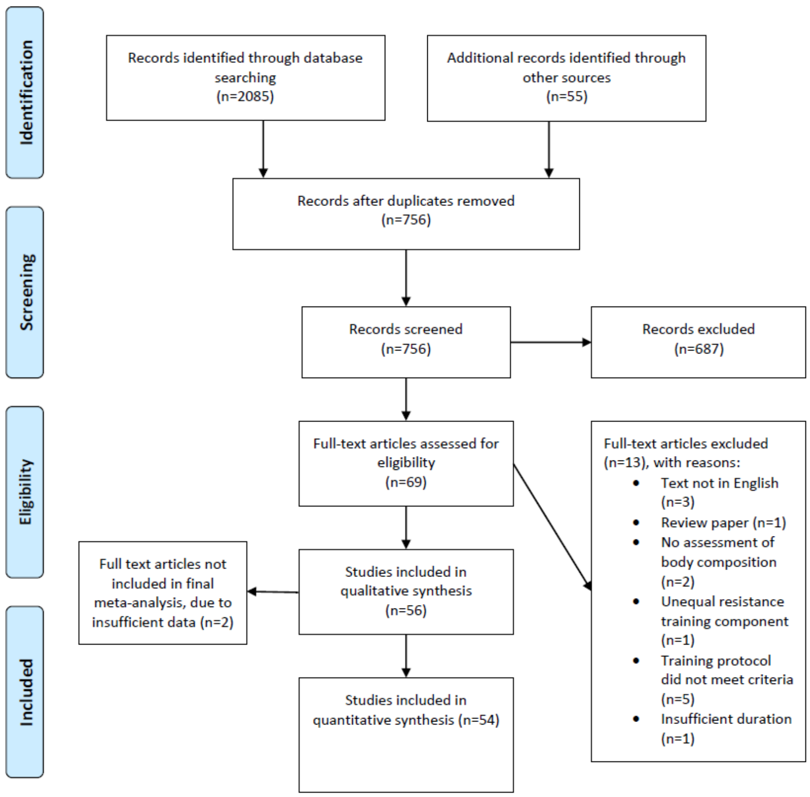

Figure 1. PRISMA Flow Diagram

Screening/Coding of Studies

Search/screening was carried out separately by two researchers (DP and AR). These researchers read all titles and abstracts and then reviewed full texts for papers deemed relevant based on title and abstract. Decisions then were made as to whether a study warranted inclusion based on the stated criteria. Any disputes on the inclusion of a given study were settled by a third researcher (MCM).

After determining which studies met inclusion, two researchers (DV and HZ) separately coded the following variables for each study: authors, title and year of publication, sample size, sex, body mass index (BMI), training status, age, description of the training intervention (duration, intensity, frequency, modality), work matched (yes/no), nutrition controlled (yes/no), method for body comp assessment (e.g. DXA, BodPod, BIA, hydrostatic weighing, skinfolds, MRI, CT, ultrasound), number of adverse effects associated with the training intervention, adherence to the given training program, mean pre- and post-study body composition value in addition to pre-post change scores with the corresponding standard deviation or standard error, and where change score standard deviations were not reported we extracted information to allow their calculation including confidence intervals for change scores or within group pre-post t statistics or p values (where p values were reported only to the studies level of alpha [e.g., $p < 0.05$] we took this as a conservative value). In cases where body composition data were not reported numerically, we either extracted the data from graphs when available via online software, or attempted to contact the study's authors. Coding was cross-checked between reviewers, with any discrepancies resolved by mutual consensus. Consistent with the guidelines of Cooper et al. (25), 30% of the included studies were randomly selected for re-coding to assess for potential coder drift by a third researcher (BM). Agreement was calculated by dividing the number of variables coded the same by the total number of variables; acceptance required a mean agreement of 0.90. Extracted data was also double checked after this process by the lead author (JS) prior to analysis.

Methodological quality and certainty of evidence

Two of the authors independently evaluated each study (JG and BJS) using the 11-point Physiotherapy Evidence Database (PEDro) scale, which has been validated to assess the methodologic quality of randomized trials (26) with acceptable inter-rater reliability (27). Any discrepancies in agreement on a given scale item were settled by mutual agreement between the researchers. Given that it is infeasible to blind participants and investigators in supervised exercise interventions, we opted to remove the assessment items specific to blinding (numbers 5, 6, and 7 in the scale). After eliminating these items, this created a modified 8-point PEDro scale with a maximum value of 7 (the first item is excluded from the total score). The qualitative methodological ratings were amended similar to those used in previous exercise-related systematic reviews (28) as follows: "excellent" (6-7 points); "good" (5 points); "moderate" (4 points); and "poor" (0-3 points). We also followed the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework (29) for evaluating the certainty of evidence with respect to our primary pre-registered outcomes (absolute fat mass, and absolute lean/fat free mass). We used the GRADEpro online tool (30) for this assessment and generation of the summary of findings table. It should be noted though that we did not pre-register the use of the GRADE approach to evaluating the evidence presented but decided a posteriori that the assessment would enhance the ability to draw practical inferences from the data.

Statistical Analyses

Quantitative synthesis of data was performed with the 'metafor' (31) package in R (v 4.0.2; R Core Team, https://www.r-project.org/). All analysis code and data are openly available in the supplementary materials (https://osf.io/6karz/). Studies were grouped by design (i.e., within- or between-group), and depending on reporting in individual studies either post or delta comparisons, or pre-post comparison designs (11) for the purposes of appropriate calculation of standardized effects (Hedge's *g*) using the escalc function in metafor. We used the pooled group baseline standard deviation as the numerator as per Morris (29). Standardized effect sizes were interpreted as per Cohen's (32) thresholds: trivial (<0.2), small (0.2 to <0.5), moderate (0.5 to <0.8), and large (≥0.8). Standardized effects were calculated in such a manner that a positive effect size value favors the intervention conditions.

Because there was a nested structure to the effect sizes calculated from the studies included (i.e., multiple effects nested within groups and nested within studies), multilevel mixed effects meta-analyses with both study and intra-study groups included as random effects in the model were performed. Cluster robust point estimates and precision of those estimates using 95% compatibility (confidence) intervals (CIs) were produced, weighted by the inverse sampling variance to account for the within- and between-study variance (τ^2). Restricted maximal likelihood estimation was used in all models. Two main models were produced for both pre-registered main outcomes (absolute fat mass and lean mass), including all standardized effect sizes to provide a general estimate of the comparative treatment effects. All other models were considered secondary and exploratory analyses.

For all models, we avoided dichotomizing the existence of an effect for the main results and therefore did not employ traditional null hypothesis significance testing, which has been extensively critiqued (33, 34). Instead, we considered the implications of all results compatible with these data, from the lower limit to the upper limit of the interval estimates, with the greatest interpretive emphasis placed on the point estimate. Given the large number of included studies and effects, main models are visualized using ordered caterpillar plots to aid interpretation as opposed to traditional forest plots containing study characteristics. Note that all study characteristics are available in the data file in the supplementary materials (https://osf.io/a29m4/).

The risk of small study bias was examined visually through contour-enhanced funnel plots. Q and I^2 statistics also were produced and reported (35). A significant Q statistic is typically considered indicative of effects likely not being drawn from a common population. I^2 values indicate the relative degree of heterogeneity in the effects that are not due to sampling variance and are qualitatively interpreted as: 0-40% not important, 30-60% moderate heterogeneity, 50-90% substantial heterogeneity, and 75-100% considerable heterogeneity (36). For within participant effects, pre-post correlations for measures are often not reported in original studies; thus, for those studies were we had standard deviations for pre-, post-, and change scores (or were able to calculate the latter from confidence intervals, t statistics, or p values) we calculated the pre-post correlations directly as,

$$r_{pre-post} = \frac{SD_{pre}^2 + SD_{post}^2 + SD_{change}^2}{2 * SD_{pre} * SD_{post}}$$

and imputed the median correlation coefficient to studies as an appropriate estimate of the population parameter.

In addition to the main models, we secondarily produced models for relative fat and lean mass (i.e., as a percentage of body mass), and refit all models using delta scores (i.e., changes) of outcomes in the raw units of measurement (i.e., kilograms and percentages) to facilitate interpretation in a complementary fashion. We also produced models where studies included a non-training control arm, that examined the between condition treatment effects for both IT vs CON, and MICT vs CON, to determine the 'within-condition' effect estimates on both their standardized and raw scales.

We planned to conduct exploratory subgroup and moderation analyses across standardized effects for the following: work matched/unmatched, modality of training (ambulatory, cycling, or other), sex (proportion of sample as males), age (years), BMI (kg.m^2), intervention characteristics including level of intensity of effort for IT (i.e. SIT vs HIIT), within session IT interval number and duration and their interaction, duration of MICT sessions, the difference (i.e., MICT minus IT) in total weekly exercise duration (frequency * duration), and duration of interventions (weeks), method of body composition measurement (DXA, BIA, skinfolds, etc.), body composition region of measure (upper, lower, trunk), and whether nutrition was controlled or uncontrolled. Note, we originally mentioned exploration of moderators for both standardised and unstandardised effects in our pre-registration. However, we ultimately opted to just explore standardised effects for absolute fat mass and lean mass outcomes to compliment and explore heterogeneity in our main models. Further, we adapted the operationalization of some moderators (e.g., intervention characteristics such as total weekly exercise duration) and some we could not explore fully given the number of effects available for certain sub-groups (these are noted in the analysis code). We also fit further (not pre-registered) models to examine adherence and dropout proportions, as well as a Poisson regression model for adverse event count data (per 1000 person-sessions), with the same multilevel structure and specifications as the main models.

As a final exploratory (not pre-registered) analysis, we examined the variation in responses between both IT and MICT conditions. We sought to identify whether there was evidence of 'true' inter-individual variation from within-participant variability and/or participant-by-treatment interaction in responses to interventions by comparing the standard deviations for change scores with those of non-exercise control conditions (21, 37). A model comparing the log-transformed variability ratio [i.e., the ratio of two standard deviations; (22)] was produced where ratios were calculated such that positive values showed that intervention condition variation exceeded control condition variation thus suggesting evidence of 'true' inter-individual response variation. Where studies did not report change score standard deviations, or we were unable to calculate it directly, this was estimated using the imputed median pre-post correlation coefficient noted above as,

$$SD_{change}\sqrt{SD_{pre}^{2}+SD_{post}^{2}-(2*r_{pre-post}*SD_{pre}*SD_{post})}$$

Note that, given the different measurement devices used in individual studies, we accepted pragmatically the inherent assumptions built into this comparison of a constant Gaussian measurement error (i.e., that measurement error does not scale in a non-linear fashion with measured scores).

Results

Search Results

From the initially reviewed 2085 search results, a total of 56 studies were determined to meet inclusion criteria for our analysis. Two studies stated that body composition measures were performed but did not report information on this outcome in the manuscript (38, 39). Attempts to obtain the data from the corresponding authors proved unsuccessful. Thus, we analyzed 54 studies that compared the effects of IT and MICT on measures of body composition. Table 1 presents a summary of the methods of the included studies. Table 2 presents descriptive information as to the included studies. Figure 2 shows the contour enhanced funnel plot for all effects from these studies. Inspection of the funnel plot did not reveal any obvious small study bias.

Table 1. Methods of included studies

Study	Sample Population (age)	Duration (wks)	Group (n)	Modality/Intensity	Frequency (wk)	Time per session
Araujo et al. (2012)	Obese children (aged 8-12)	12	MICT: 15 IT: 15	MICT: 80% of peak heart rate IT: 3-6 sets of 60-s sprint at 100% of the peak velocity with 3-min active recovery period at 50% of the exercise velocity.	MICT: 2x IT: 2x	MICT: 30-60 mins IT: 9-18 mins
Boer et al. (2013)	Young adults with intellectual disabilities (aged 16-18 yrs)	15	MICT: 15 IT: 17 CON: 14	MICT: Cycling, walking/running, stepping at 30% peak watts IT: First 7 weeks: 10 sprint bouts x 15s at ventilatory threshold (100+ RPM), 45s recovery period at 50RPM Weeks 8-15: intensity increased to 110% VT	MICT: 2x IT: 2x	MICT: 40 mins IT: 40 mins
Boer et al. (2016)	Down syndrome adults (mean age 34 yrs)	12	MICT: 13 IT: 13 CON: 16	MICT: Continuous cycling/walking at 70-80% VO2 peak, 85% after week 6 IT: 10 x 30s sprints, 90s rest period	MICT: 3x IT: 3x	MICT: 30 mins IT: 30 mins
Buchan et al. (2011)	Adolescents (mean age 16 yrs)	7	MICT: 16 IT: 17 CON: 24	MICT: Running at moderate intensity at 70% VO2 max (VO2 max retested at week 4) IT: 4-6 all-out sprints x 30s, 30s recovery period (20s recovery period for week 7)	MICT: 3x IT: 3x	MICT: 20 mins IT: 16 mins
Camacho-Cardenosa et al. (2016)	Children (mean age: 11 yrs)	8	MICT: 16 IT: 18	MICT: Running at 65-75% HRmax IT: 3-6 bouts, 20s max-effort sprint, 60s rest period (40s at week 5, 20s at week 8)	MICT: 3x IT: 3x	MICT: 4-9 mins IT: 4-9 mins

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Cheema et al. (2015)	Obese adults (mean age: 39 yrs)	12	MICT: 6 IT: 6	MICT: Brisk walking at 4 METs IT: 4-7 intervals at a 2:1 ratio, then 5 boxing drills x 3 intervals at a 2:1 ratio, RPE 15-17 (>75% HRmax)	MICT: 4x IT: 4x	MICT: 50 mins IT: 50 mins
Cocks et al. (2016)	Obese adult men (mean age: 25 yrs)	4	MICT: 8 IT: 8	MICT: Continuous cycling @ 65% VO2 peak IT: 4-7 sprints x 30s at 200% W-max, 120s at 30W in-between	MICT: 5x IT: 3x	MICT: 40-60 mins IT: 10-17.5 mins
Devin et al. (2016)	Colorectal cancer survivors (mean age: 62 yrs)	4	MICT: 14 IT: 21	MICT: Continuous cycling at 50-70% HRpeak IT: 4 cycling intervals x 240s at 85-95% HRpeak, 180s active rest	MICT: 3x IT: 3x	MICT: 50 mins IT: 38 mins
Dias et al. (2018)	Obese children (aged 7-16 yrs)	12	MICT: 22 IT: 18 CON: 16	MICT: 60-70% HRmax IT: 4 intervals of 240s at 85-95% HRmax, 180s active recovery at 50-70% HRmax	MICT: 3x IT: 3x	MICT: 44 mins IT: 28 mins
Earnest et al. (2013)	Adult men at risk for insulin resistance (mean age: 48 yrs)	12	MICT: 16 IT: 21	MICT: Worked towards 6Kcal/kg per week for 6 weeks (+2 per week until 12 Kcal/kg per week) treadmill at 50-70% VO2 max IT: Performed MICT protocol until week 6 then transitioned, 2-8 bouts of 60s at 90-95% VO2 max, 60s recovery period at 50% VO2 max	MICT: 3-4x IT: 3-4x	MICT: Work-dependent IT: 4-16 mins

Eimarieskandari et al. (2012)	Obese young women (mean age: 22 yrs)	8	MICT: 7 IT: 7 CON: 6	MICT: Continuous treadmill at 50-70% at HRpeak IT: 4 intervals of 240s at 85-95% HRpeak, 180s active rest	MICT: 3x IT: 3x	MICT: 41 mins IT: 33 mins
Elmer et al. (2016)	Sedentary young men (mean age: 21 yrs)	8	MICT: 6 IT: 6	MICT: Continuous treadmill at 70-80% VO2 max IT: 12 intervals of 60s at 90-110% VO2 max, 60s rest period	MICT: 3x IT: 3x	MICT: 30 mins IT: 30 mins
Fisher et al. (2015)	Obese young men (aged 17-22 yrs)	6	MICT: 13 IT: 15	MICT: Cycling at 55-65% VO2 peak IT: 4 intervals of 240s at 15% APmax, then 30s at 85% APmax, then 120s at 15% APmax	MICT: 5x IT: 3x	MICT: 45-60 mins IT: 20 mins
Galedari et al. (2017)	Overweight men (aged 20-40 yrs)	12	MICT: 12 IT: 10	MICT: Walking/jogging at 65% HRmax IT: 6-12 intervals of 60s at 90-95% HRmax, 60s active rest	MICT: 3x IT: 3x	MICT: 18-35 mins IT: 12-24 mins
Gillen et al. (2016)	Sedentary young men (mean age: 27 yrs)	12	MICT: 10 IT: 9 CON: 6	MICT: Continuous cycling at 70% HRmax IT: 3 all-out intervals of 20s at 0.5kg/kg resistance, 120s low-intensity active rest	MICT: 3x IT: 3x	MICT: 45 mins IT: 10 mins
Gripp et al. (2021)	Male police officers (mean age: 39 yrs)	8	MICT: 11 IT: 11	MICT: Continuous running at 60-75% V-shuttle max IT: 7-10 intervals of 85-100% V-shuttle max (V-shuttle based on individual shuttle test results)	MICT: 3x IT: 3x	MICT: 27-8-33.4 mins IT: 14.8-19.1 mins
Higgins et al. (2016)	Overweight young women	6	MICT: 29 IT: 23	MICT: Continuous cycling at 60-70% HRR	MICT: 3x IT: 3x	MICT: 20-30 mins

	(mean age: 20 yrs)			IT: 5-7 all-out intervals of 30s, 240s active recovery		IT: 22.5-31.5 mins
Hwang et al. (2016)	Healthy, sedentary older adults (aged 55-79 yrs)	8	MICT: 14 IT: 15 CONT: 14	MICT: 70% of peak heart rate IT: 4 x 4 minutes intervals at 90% of peak heart rate with 3 x3 minute active recovery periods at 70% of peak heart rate.	MICT: 4x IT: 4x	MICT: 47 mins IT: 40 mins
Keating et al. (2014)	Inactive, overweight adults (aged 18-55 yrs)	12	MICT: 11 IT: 11 CONT: 11	MICT: 50-65% VO2peak IT: cycling, 4-6 sets of 30-60 s at 120% VO2peak with 120-180 s at 30 W.	MICT: 3x IT: 3x	MICT: 30-45 mins IT: 20-24 mins
Koubaa (2013)	Obese adolescents (mean age: 13 yrs)	12	MICT: 15 IT: 14	MICT: 60-70% of vVO2max IT: running for 2 mins at 80-90% of vVO2max followed by recovery periods of 1 min.	MICT: 3x IT: 3x	MICT: 30-40 mins
Lunt et al. (2014)	Overweight, inactive adults (aged 35–60 yrs)	12	MICT: 17 IT (AIT): 11 IT (MVIT): 16	MICT: Walking, 65-75% of HRmax IT (AIT): jogging, 4 cycles of 4 mins at 85-95% HRmax followed by 3 mins recovery at 65-75% HRmax. IT (MVIT): 30 s of “all out” exercise followed by 4 mins of low intensity recovery.	MICT: 3x IT (AIT): 3x IT (MVIT): 3x	MICT: 48 mins IT (AIT): 40 mins IT (MVIT): 24.5-40 mins
Macpherson et al. (2011)	Healthy, recreationally active young adults (mean age: 23 yrs)	6	MICT: 10 IT: 10	MICT: running, 65% of VO2max IT: 4-6 bouts of 30 s maximal running efforts with 4 mins of recovery (active recovery encouraged)	MICT: 3x IT: 3x	MICT: 30-60 mins IT: 18-27 mins
Mäder et al. (2001)	Overweight, untrained men (aged 28-46 yrs)	10	MICT: 7 IT: 7	MICT: 50% of VO2max	MICT: 3x IT: 3x	MICT: 50 mins IT: 50 mins

				IT: 25 sets of 80 s at 35% VO2max followed by 40 s at 80% VO2max.		
Magalhães et al. (2020)	Adults with type 2 diabetes (mean age: 59 yrs)	52	MICT: 24 IT: 19 CONT: 24	MICT: cycling 40-60% of HRR IT: cycling, 2 mins at 70-80% of HRR with 1 min at 40-60% of HRR. 1 min at 90% of HRR with 1 min resting at 40-60% of HRR.	MICT: 3x IT: 3x	MICT: 45 ± 7.1 mins IT: 33.1 ± 6.4 mins
Maillard et al. (2016)	Postmenopausal women with type 2 diabetes (mean age: 69 yrs)	16	MICT: 8 IT: 8	MICT: 55-60% of individual HR reserve IT: 60 cycle (maximum) of 8 s at 77-85% HRmax with active recovery of 20-30 rpm for 12 s.	MICT: 2x IT: 2x	MICT: 40 mins IT: 25 mins
Martínez et al. (2016)	Children (aged 7-9 yrs)	12	MICT: 56 IT: 38	MICT: 20 mins of moderate-intensity aerobic exercises and games followed by 20 mins of sport. IT: 20 mins of 10-20 s of high-intensity intermittent exercises followed by 20 mins of sports activities.	MICT: 2x IT: 2x	MICT: 40 mins IT: 40 mins
Martins et al. (2016)	Sedentary Obese Adults (aged 34 yrs)	12	MICT: 14 IT: 16 ½ IT: 16	MICT: 70% of peak HR IT: 8s of maximal intensity sprint intervals on a bike at 85-90% of peak HR, with 12 second rest intervals pedaling as slow as possible. Sequence continued until the 250-kcal target was met. ½ IT: Same as IT but with a 125 Kcal target.	MICT: 3x IT: 3x ½ IT: 3x	MICT: 32 mins(avg.) IT: 20 mins(avg.) ½ IT: 10 mins (avg.)
Matsuo et al. (2014)	Sedentary adult men (aged 29 yrs)	8	MICT: 12 IT: 12	MICT: 60%-65% VO2max	MICT: 3x IT: 3x	MICT: 45 min

				IT: 3, 3-minute intervals of high intensity cycling at 80-85% VO2max with 2 active rest intervals.		IT: 18 minutes total including 5 minutes of combined warm-up and cool down.
Matsuo et al. (2015)	Adult men with metabolic syndrome (mean age: 48 yrs)	8	MICT: 13 IT: 13	MICT: cycling at 60%-65% of VO2peak IT: 3 sets of 3-min cycling at 80-85% VO2peak with a 2-min active rest between sets at 50% VO2peak	MICT: 3x IT: 3x	MICT: 45 mins IT: 18 mins
Mohr et al. (2014)	Sedentary premenopausal women (mean age: 45 yrs)	15	MICT: 21 IT: 21 CON: 20	MICT: Moderate intensity swimming at ~70% HRmax. IT: 6–10 × 30 s all-out swimming with 2 min recovery in between each bout at.~90% HRmax	MICT:3x IT: 3x	MICT: 1 hour IT: 15-25 minutes total.
Moreira et al. (2008)	Overweight adults (mean age: 40 yrs)	12	MICT: 8 IT: 8 CON: 7	MICT: Biking at 10% lower than anaerobic threshold. IT: Biking at 20% above anaerobic threshold with an exercise:pause ratio of 2:1.	MICT: 3x IT: 3x	Both groups had completed 20 minutes in the first week, with increments of 10 minutes per week until a total of 60 minutes per session was reached in the fourth week.
Morrissey et al. (2018)	Obese adolescents (mean age: 15 yrs)	12	MICT: 13 IT: 16	MICT: Boxing and Nordic walking at 60%-75% of maximal HR.	MICT: 3x IT: 3x	MICT: 40 to 60 mins. IT: 24 to 32mins

				IT: 4 to 6 intervals of 2min-2 min 30 s in duration at 90–95% of HRmax interspersed by 1min 30s intervals at 55% of HRmax		
Murphy et al. (2015)	Obese adolescents (mean age: 14 yrs)	4	MICT: 8 IT: 10	MICT: 65% HRmax IT: 1-minute vigorous treadmill exercise at 80% to 90% HRmax interspersed with 2-minute recovery intervals at 60% HRmax	MICT: 3x IT: 3x	MICT: 50 mins
Nalcakan (2014)	Recreationally active men (mean age: 21.7 yrs)	7	MICT: 7 IT: 8	MICT: Cycling at 60% of VO2max. IT: 4-6 Wingate sprints (resistance = 7.5% of subject BW) with 4.5mins recovery	MICT: 3x IT: 3x	MICT: 30-50 mins IT: 30 mins
Nybo et al. (2010)	Untrained men (mean age: 33 yrs)	12	MICT: 9 IT; 8 CON:11	MICT: 80% HRmax IT: Five intervals of 2 min of near-maximal running (HR above 95% of their HRmax at the end of the 2-min period interspersed by 1 minute rest.	MICT: 3x IT: 2x (attempted 3 but accomplished 2 on average due to injuries or other reasons)	MICT: 1 hour IT: 20 minutes
Oh et al. (2017)	Sedentary obese males (mean age: 48.4 yrs)	12	MICT: 13 IT: 20	MICT: Cycling at 60-65% VO2Max IT: 3 sets of 180-s cycling at 80-85% VO2Max with 120-s recovery period at 50% VO2Max	MICT: 3x IT: 3x	MICT: 40 mins IT 13 mins
Panissa et al. (2016)	Untrained women (mean age: 28.4 yrs)	6	MICT: 12 IT: 11	MICT: Cycling at 70% HRmax IT: Cycling 15 sets 60-s at 90% HRmax with 30s	MICT: 3x IT: 3x	MICT: 29 mins IT: 22 mins

				recovery period at 60% HRmax		
Pasetti et al. (2012)	Untrained obese women (mean age: 46 yrs)	12	MICT: 12 IT: 18	MICT: Deep water running at 65-85% HRR IT: Deep water running 8-15 15s sprints with 30s recovery interspersed with 5-14 min intervals at 70-75% HRmax	MICT: 3x IT: 3x	MICT: 47 mins IT: 47 mins (including recovery periods)
Ramírez-Vélez et al. (2017)	Healthy physically inactive adults (mean age: 32 yrs)	12	MICT: 9 IT: 11	MICT: Treadmill, 60-80% HRR IT: Treadmill, 4 sets 240-s at 85-95% peak HRR with 240-s recovery period at 65% peak HRR	MICT: 3x IT: 3x	MICT: 20-65 mins (including warm up and cool down) IT: 35 to 55 mins (including warm up and cool down)
Ramos et al. (2016)	Adults with metabolic syndrome (mean age: 57 yrs)	16	MICT: 21 IT (a): 22 IT (b): 23	MICT: Cycling, 60-70% of peak heart rate IT (a) Cycling, 4HIIT group- 4 240-s sets at 85-95% peak heart rate with 180-s recovery period at 50-70 peak heart rate IT (b) Cycling, 1HIIT group- 1 set 240-s at 85-95% peak heart rate with 180-s cool down at 60-70% peak heart rate	MICT: 5x IT (a): 3x IT (b): 3x	MICT: 30 mins IT (a): 4HIIT, 38 mins (including warm up and cool down). IT (b): 1 HIIT, 17 mins (including warm up and cool down)
Reljic et al. (2018)	Sedentary adults (mean age: 31 yrs)	8	MICT: 7 IT (a): 9 IT (b): 11	MICT: Cycling, 65-75% HRmax IT (a): 2x4 HIIT, cycling 2 sets 240-s at 85-95% HRMax with 120-s active rest	MICT: 2x IT (a): 2x IT (b): 2x	MICT: 38 mins (including warm up and cool down) IT (a): 15 minutes

				IT (b): 5x1 HIIT, cycling 5 sets 60-s at 85-95% HRMax with 60-s active rest		(including warm up and cool down) IT (b): 14 mins (Including warm up and cool down)
Sasaki et al. (2014)	Sedentary males (age not reported)	4	MICT:12 IT: 12	MICT: Cycling, 45% VO2Max IT: Cycling, 10 sets, 60-s at 85% VO2Max with 30s rest period between sets	MICT:3x IT:3x	MICT: 22 mins IT: 15 mins (including rest periods)
Schjerve et al. (2008)	Obese adults (mean age: 46 yrs)	12	MICT: 13 IT:14	MICT: Treadmill, 60-70% HRMax IT: Treadmill, 4 sets 240-s at 85-95% HRMax with 180-s rest periods at 50-60% HRMax	MICT:3x IT: 3x	MICT: 47 mins IT: 42 mins (including warm up and cool down)
Shepherd et al. (2013)	Sedentary males (mean age: 2 yrs)	6	MICT: 8 IT: 8	MICT: Cycling, ~65% VO2Peak IT: Cycling, 4-6 30-s 'all out' sprints (Wingate test) with 270-s rest between each test	MICT:5x IT:3x	MICT: 40 to 60 mins IT: 20-30 mins (including rest periods)
Shepherd et al. (2015)	Overweight adults (mean age: 42 yrs)	10	MICT: 44 IT: 46	MICT: Cycling, ~70% MHR IT: Cycling, >90% MHR, repeated sprints of 15-60-s, interspersed with periods of recovery cycling	MICT: 5x IT: 3x	MICT: 30-45 min IT: 18-25 min
Shing et al. (2013)	Trained young adults (mean age: 19 yrs)	8	MICT: 7 IT: 7	MICT: Rowing, Blood Lactate Concentrations of 2-3 mmol/L IT: Rowing, 8 2.5-min intervals at 90% of mean 4-min maximal power output achieved during the incremental exercise test.	MICT: 2x IT: 2x	MICT: 35/40 min IT: 27-55 min (including recovery)

				Recovery duration was until HR returned 70% MHR, at 40% of mean maximal power output		
Sijie et al. (2012)	Overweight Young Adults (mean age: 20 yrs)	12	MICT: 16 IT: 17 CON: 19	MICT: Walking/Jogging, HR associated with 50% of VO2max IT: Running, 5 3-min intervals at the HR associated with 85% VO2max with 3 min active rest at HR associated 50% VO2max between each interval	MICT: 5x IT: 5x	MICT: 55 min IT: 42 min (Including warm up and cool down)
Sim et al. (2015)	Overweight Males (mean age: 31 yrs)	12	MICT: 10 IT: 10 CON: 10	MICT: Cycling, ~60% VO2peak IT: Cycling, 15-s at a power output equivalent to ~170% VO2peak with an active recovery period of 60-s at a power output equivalent to ~32% VO2peak Relative total work was matched between both groups	MICT: 3x IT: 3x	MICT: 30-45 min IT: 30-45 min
Starkoff et al. (2014)	Obese Children (mean age: 15 yrs)	6	MICT: 13 IT: 14	MICT: Cycling, 65-70% APMHR IT: Cycling, 10 2-min bouts at 90-95% APMHR, with 1-min of active recovery at 55% APMHR between each bout	MICT: 3x IT: 3x	MICT: 40 min IT: 40 min (Including warmup and cool down)
Thomas et al. (1984)	Healthy Untrained Adults (aged 18-32 yrs)	12	MICT A: 14 MICT B: 18 IT: 15	MICT A: Running, 4-mile, 75% MHR MICT B: Running, 2 mile, 75% MHR	MICT: 3x IT: 3x	MICT A: ~32 min/ ~500 cal/session

				IT: Running, 8 bouts of 60-s intervals at 90% MHR followed by 180-s rest between each bout		MICT B: ~16 min/ ~250 cal/session IT: 29 min
Trapp et al. (2008)	Healthy Inactive Young Females (mean age: 21 yrs)	15	MICT: 15 IT: 15	MICT: Cycling, 60% VO2peak IT: Cycling, maximum of 60 bouts of 8s:12s ratio of sprinting and slow pedaling	MICT: 3x IT: 3x	MICT: 20-50 min IT: 15-30 min (Including warmup and cool down
Wallman et al. (2009)	Obese Adults (mean age: 43 yrs)	8	MICT: 6 IT: 7 CON: 8	MICT: Cycling, 50-65% VO2 peak IT: 1:2 min ratio of high to low intensity of 90-105% VO2peak and 30-45% VO2peak	MICT: 4x IT: 4x	MICT: 30 min IT:30 min (Including recovery)
Winding et al. (2018)	Overweight Adults (mean age: 56 yrs)	11	MICT: 12 IT: 13 CON: 7	MICT: Cycling, 50% Wpeak IT: Cycling, 1-min at 95% Wpeak, with 1-min active recovery at 20% Wpeak between each bout.	MICT: 3x IT: 3x	MICT: 135 min IT: 75 min (Including the warmup)
Zhang et al. (2017)	Overweight Young Females (mean age: 21 yrs)	12	MICT: 15 IT: 15 CON: 13	MICT: Cycling, 60% VO2max until 300 kJ of work is reached IT: Cycling, repeated 4-min bouts at 90% VO2max with 3-min passive recovery between bouts until 300 kJ of work is reached	MICT: 3-4x IT: 3-4x	MICT: Until 300kJ of work was reached IT: Until 300kJ of work was reached

Table 2. Summary descriptive characteristics of studies	
Characteristic	**Number of Groups Within Studies = 60**
Age (years)	30 (21, 44)
Unknown	1
Sex (% Male)	54 (32, 100)
BMI (kg.m^2)	28.3 (25.4, 30.5)
Unknown	7
Training Status	
Recreationally active	1 (1.7%)
Trained	1 (1.7%)
Untrained	58 (97%)
Was Nutrition Controlled?	
No	31 (52%)
Yes	29 (48%)
Included Caloric Deficit?	
No	57 (95%)
Yes	3 (5.0%)
Include Resistance Training Intervention?	
No	59 (98%)
Yes	1 (1.7%)
Were IT/MICT Work Matched?	
No	34 (57%)
Yes	25 (42%)
Yes, matched for time	1 (1.7%)
Intervention Duration (weeks)	12 (8, 12)
IT Frequency (median days per week)	
2	8 (13%)
3	44 (73%)
3.5	2 (3.3%)
4	3 (5.0%)
4.5	2 (3.3%)
5	1 (1.7%)
MICT Frequency (median days per week)	
2	8 (13%)
3	38 (63%)
3.5	2 (3.3%)
4	3 (5.0%)
4.5	2 (3.3%)
5	7 (12%)
Was IT Performed as SIT or HIIT?	

Table 2. Summary descriptive characteristics of studies	
Characteristic	**Number of Groups Within Studies = 60**
HIIT	45 (75%)
SIT	15 (25%)
IT Interval Number Performed	5 (4, 10)
Unknown	5
IT Interval Duration (median seconds)	60 (30, 180)
IT Total Exercise Duration (minutes)	9.4 (3.4, 16.0)
MICT Session Duration (minutes)	38 (30, 45)
Unknown	3
IT Adherence (% Sessions)	90 (83, 98)
Unknown	24
MICT Adherence (% Sessions)	90 (84, 97)
Unknown	25
IT Adverse Event Number	
0	12 (63%)
1	2 (11%)
2	2 (11%)
3	1 (5.3%)
4	1 (5.3%)
5	1 (5.3%)
Unknown	41
MICT Adverse Event Number	
0	10 (67%)
1	3 (20%)
2	2 (13%)
Unknown	45

Note: Values are Median (IQR) for continuous variables, and n (%) for categorical

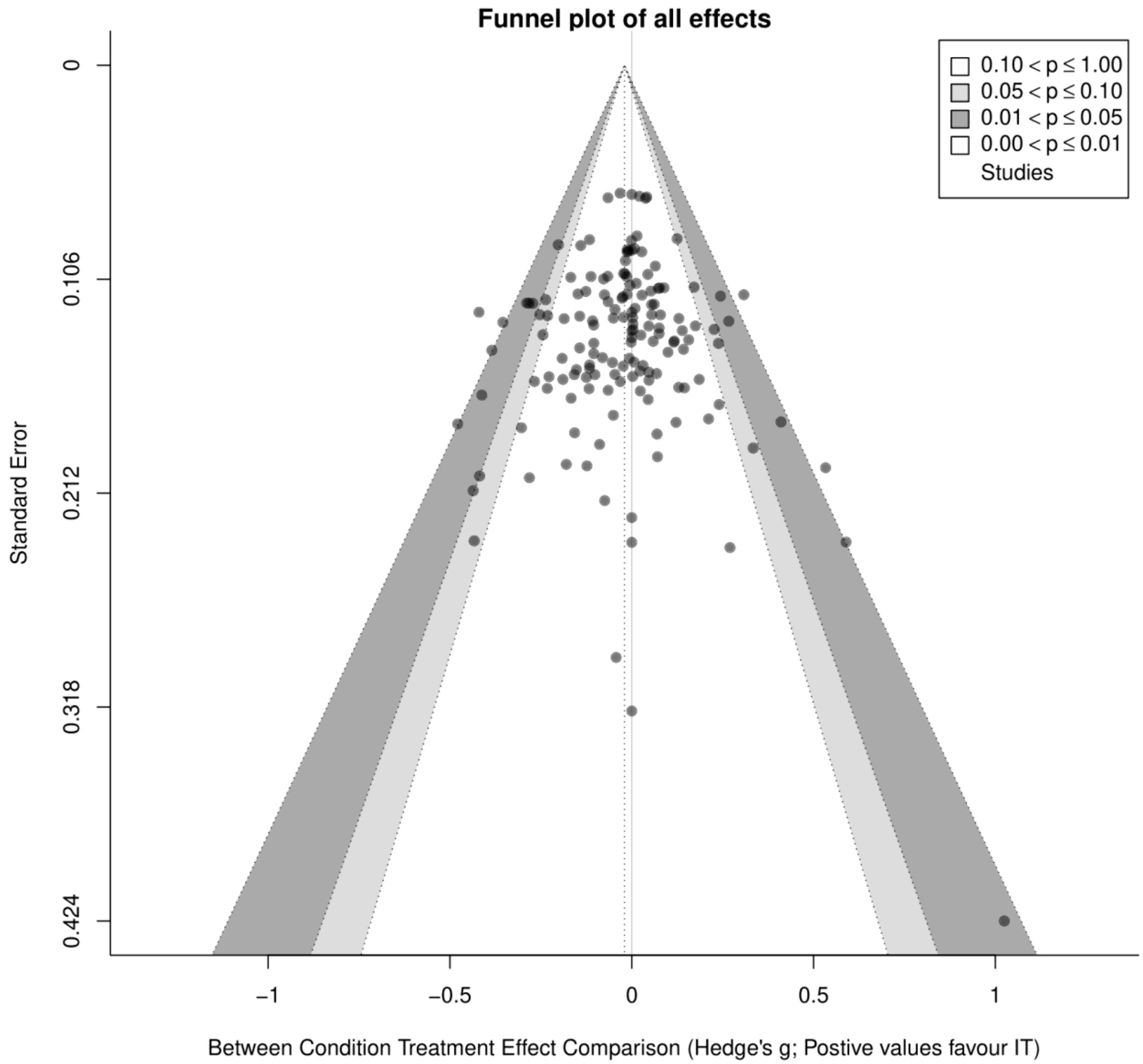

Figure 2. Contour enhanced funnel plot of all effects.

Methodological Quality

Study quality, as assessed by the PEDro scale, had a mean rating of 5.6, indicating the overall pool of studies to be of good quality. A total of 32 studies were rated as being of excellent quality, 21 studies were rated as being of good quality, and 1 study was rated as being of fair quality; no study in the analysis was deemed to be of poor quality.

Main Models

Fat Mass

The main model for all fat mass effects (55 across 29 clusters [median = 1, range = 1-6 effects per cluster]) revealed a trivial standardized point estimate with a high precision for the interval estimate (-0.02 [95%CI = -0.07 to 0.04]), with somewhat moderate heterogeneity ($Q_{(54)}$ = 79.08, p 0.015, I^2 = 36%). Figure 3 presents all standardized effects and interval estimates for fat mass outcomes across studies in an ordered caterpillar plot.

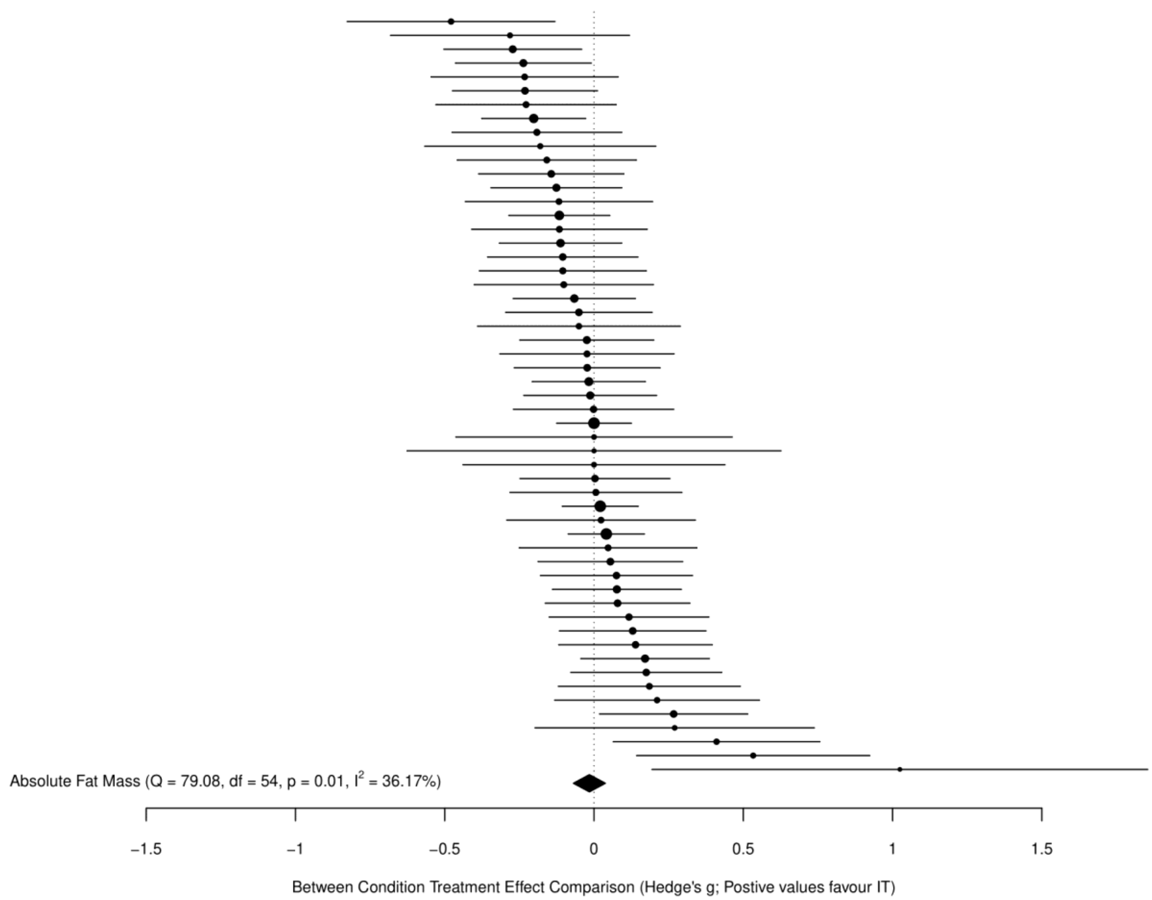

Figure 3. Ordered caterpillar plot of all absolute fat mass effects.

Lean Mass

The main model for all lean mass effects (34 across 27 clusters [median = 1, range = 1-3 effects per cluster]) revealed a trivial standardized point estimate with a high precision for the interval estimate (-0.0004 [95%CI = -0.05 to 0.05]), with negligible heterogeneity ($Q_{(33)}$

= 37.77, p = 0.26, I^2 = 16%). Figure 4 presents all standardized effects and interval estimates for lean mass outcomes across studies in an ordered caterpillar plot.

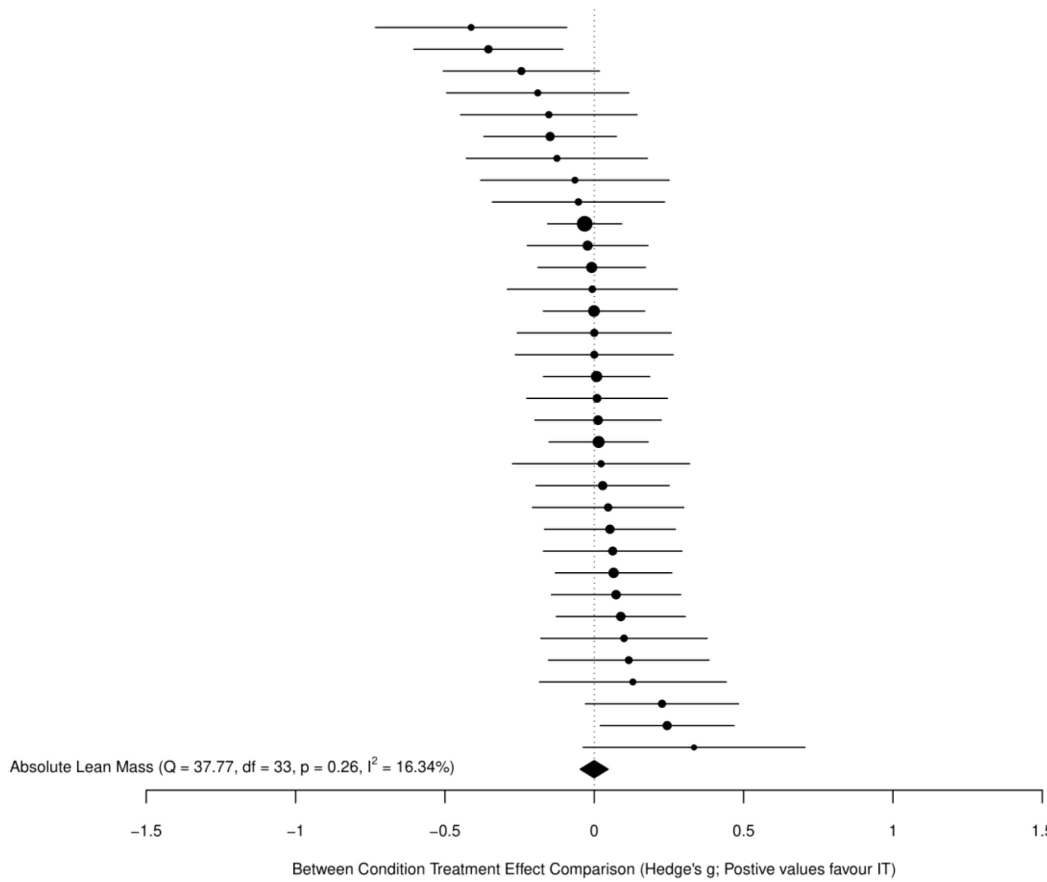

Figure 4. Ordered caterpillar plot of all absolute lean mass effects.

GRADE Summary of Findings for Main Outcomes

For both fat mass and lean mass there was a 'high' certainty of evidence with respect to the effects identified. It was deemed that there was no serious risk of bias, inconsistency, indirectness of evidence, or imprecision in estimates, not where there other clear considerations impacting on certainty of evidence grading. Table 3 shows the GRADE summary of findings table for our main outcomes.

Table 3. GRADE summary of findings for main outcomes

Certainty assessment							№ of patients		Effect	Certainty
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	**Interval training (IT)**	**Moderate intensity continuous training (MICT)**	**Absolute (95% CI)**	
Absolute fat mass (follow up: median 12 weeks; assessed with: Air displacement plethysmography (ADP), bioelectrical impedance analysis (BIA), dual energy x-ray absorptiometry (DXA), hydrostatic weighing, magnetic resonance imaging (MRI))										
29	randomised trials	not serious	not serious	not serious	not serious	none	437	425	- Hedges *g* = **0.02 lower** (0.07 lower to 0.04 higher)	⨁⨁⨁⨁ HIGH
Absolute lean/fat free mass (follow up: median 12 weeks; assessed with: Air displacement plethysmography (ADP), bioelectrical impedance analysis (BIA), dual energy x-ray absorptiometry (DXA), hydrostatic weighing, magnetic resonance imaging (MRI))										
27	randomised trials	not serious	not serious	not serious	not serious	none	446	423	- Hedges *g* = **0.00** (0.05 lower to 0.05 higher)	⨁⨁⨁⨁ HIGH

Secondary Analyses

Between condition treatment effect models on both the raw effect scales, and when using relative fat or lean mass outcomes, showed similar outcomes to the main models reported. Thus, for brevity, these are presented in the supplementary materials (https://osf.io/3s7vz/). Caterpillar plots are also available for all secondary models.

Within-Condition Treatment Effects

All within-condition models are also available in the supplementary materials and here we report just the results for absolute fat and lean mass outcomes on standardized and raw scales. In comparison to non-intervention control groups, the IT conditions resulted in small reductions in fat mass (Hedge's g = -0.22 [95%CI = -0.36 to -0.08]; kilograms = -0.20 [95%CI = -0.34 to -0.06]), and trivial increases in lean mass (Hedge's g = 0.13 [95%CI = 0.04 to 0.22]; kilograms = 0.11 [95%CI = -0.04 to 0.26]). The MICT conditions also produced small reductions in fat mass (Hedge's g = -0.20 [95%CI = -0.36 to -0.04]; kilograms = -0.25 [95%CI = -0.39 to -0.11]), and trivial increases in lean mass (Hedge's g = 0.07 [95%CI = -0.01 to 0.16]; kilograms = 0.07 [95%CI = -0.02 to 0.15]).

Sub-Group and Meta-Regression Analyses

Sub-group and meta-regression models were not run for absolute lean mass standardized effects given the negligible heterogeneity in the main model. When exploring sub-group and meta-regression models for absolute fat mass standardized effects only two moderators—sex (proportion of males in sample) and the number of intervals performed per training session by IT—appeared to have an effect, albeit this effect was relatively small for both covariates. Again, for brevity, all sub-group and meta-regression models are included in the supplementary materials (https://osf.io/3s7vz/).

Adherence, Dropouts, and Adverse Events

There was minimal difference in adherence or dropout proportions between conditions which were relatively high and low, respectively. Adherence for IT was 91.7% [95%CI = 88.0% to 94.3%] and for MICT was 91.3% [95%CI = 87.0% to 94.2%], and dropouts for IT were 13.5% [95%CI = 9.7% to 18.3%] and for MICT were 17.8% [95%CI = 14.3% to 21.9%]. Adverse events per 1000 person-sessions (i.e., the number of events per 1000 training sessions performed) were also relatively low and with minimal difference between conditions, with values of 1.07 [95%CI = 0.28 to 4.10] and 1.07 [95%CI = 0.51 to 2.24] for IT and MICT, respectively.

Inter-Individual Response Variation

There was no clear evidence of 'true' inter-individual variation in responses from examination of the log variability ratios for either IT or MICT conditions which were -0.03 [95%CI = -0.23 to 0.18] (see https://osf.io/shuj2/) and 0.11 [95%CI = -0.05 to 0.28] (see https://osf.io/f9tv2/) respectively.

Discussion

This is the most comprehensive meta-analysis to date on the effects of intensity of effort during exercise on changes in measures of fat mass and lean mass. Further, GRADE assessment suggests high certainty in the evidence presented. Our findings provide novel insights into the use of different training strategies to bring about changes in body composition. Below we discuss the results and practical implications of our data for each outcome.

Changes in Fat Mass

It has been speculated that IT may confer superior fat loss benefits compared to MICT, primarily mediated via a greater excess post-exercise oxygen consumption (EPOC) (40). However, the overall magnitude of additional energy expenditure attributed to EPOC during IT is modest (41), and thus unlikely of practical meaningfulness from a fat loss standpoint. Other proposed benefits of IT on fat reduction include enhancements in appetite suppression, fat oxidation, and circulating catecholamines and lipolytic hormones (41). Despite this mechanistic rationale, our results do not support a superiority of IT on reductions in fat mass. Analysis of standardized between group treatment effects showed similar changes for IT and MICT in both absolute fat mass as our primary outcome (Hedge's g = (-0.02 [95%CI = -0.07 to 0.04]), and percentage body fat (Hedge's g = -0.04 [95%CI = -0.08 to 0.01]). Raw absolute fat mass changes revealed a trivial point estimate of -0.17 kg favoring MICT, though the interval estimate ranged from -0.66 kg in favor of MICT to 0.31 kg in favor of IT. Comparison of raw relative (%) fat mass changes in fat mass revealed a small point estimate of -0.30% favoring MICT, but again the interval estimate was imprecise ranging from -0.63% in favor of MICT to 0.04% in favor of IT. Taken as a whole, these findings suggest that changes in fat loss are not meaningfully influenced by the intensity of effort during exercise.

When compared to non-exercising controls, IT and MICT produced small reductions in fat mass, with minimal difference between conditions. The raw absolute fat loss amounted to -0.22 kg for IT and -0.25 kg MICT, with standardized Hedge's g ES values of 0.22 and 0.20 respectively. Relative changes in fat mass for IT and MICT showed similarly small decreases vs control, both on a raw (0.30% and 0.25%, respectively) and standardized (0.28 and 0.24, respectively) basis. None of the studies that included control conditions combined exercise with dietary intervention (i.e., caloric deficit) and thus, collectively, these data suggest that exercise alone induces a small magnitude of fat loss regardless of the intensity of effort, at least under the methods employed in current research. The observed changes in fat mass (~0.2 kg) are unlikely to be clinically or aesthetically meaningful in most populations.

The lack of overall fat loss achieved in both IT and MICT can be attributed, at least in part, to the relatively low weekly exercise dose across studies (IT, median = 28 mins [range = 3 mins to 120 mins]; MICT, median = 120 mins [range = 48 to 250]), and perhaps confounded by a corresponding increase in energy intake (42) and/or reduction in non-exercise activity thermogenesis (43). Tightly controlled research in identical twins shows prolonged daily aerobic-type exercise can induce marked reductions in fat mass under conditions of constant energy and nutrient intake (44). However, the time commitment needed to achieve these results (~100 minutes/day) is infeasible for the majority of the general public and thus of limited practical relevance. Therefore, our findings underscore the importance of dietary prescription to facilitate weight loss; however, exercise may play an important supplementary role in the process (45).

In contrast to the recent meta-analysis from Sultana et al. (10), we did identify some moderate heterogeneity in our main model leading us to explore possible moderators. For example, some evidence suggests that IT elicits greater reductions in abdominal adiposity compared to MICT (15). Given the well-established association between android fat and cardiometabolic disease (46), such an outcome would potentially have major health implications if found to be true. However, our findings refute this contention, demonstrating similar changes in abdominal fat mass between conditions. Moreover, we found relatively equal, albeit modest, fat loss occurred across the upper body, lower body and trunk regions regardless of condition, indicating that endurance-oriented exercise does not preferentially target specific fat depots. Indeed, with the exception of sex and the number of intervals performed during IT training session both of which also only had very trivial moderating effects, we did not identify any clear moderators of comparative treatment effects for fat mass.

Changes in Lean Mass

Some researchers have proposed that the performance of aerobic exercise can elicit increases in skeletal muscle hypertrophy that are comparable to resistance exercise training (13). However, a meta-analysis by Grgic et al. (47) refuted this contention, showing significantly greater hypertrophic adaptations from resistance training vs aerobic training both at the whole muscle and myofiber level. However, it should be noted that Grgic et al. (47) did not subanalyze the effects of endurance exercise intensity on hypertrophy outcomes. A recent review speculated that IT may provide sufficient stimulus to enhance muscle growth, particularly in middle-aged and older adults, as well as clinical populations (14). Further, some emerging evidence suggests that, although traditional resistance training and aerobic modality interventions may produce differing adaptations, when duration and intensity of effort matched similar strength and endurance adaptations may occur, though the impact on hypertrophy is less clear (48).

Our results suggest that endurance exercise intensity may not mediate hypertrophic adaptations. Specifically, analysis of changes in lean mass, both on an absolute and relative basis, demonstrated similar effects between IT and MICT. Between condition treatment standardized effects for absolute changes in lean mass were essentially zero ((-0.0004 [95%CI = -0.05 to 0.05]), and comparison of effects on the raw scale showed a small point estimate of 0.09 kg favoring IT, yet the interval estimate ranged from -0.18 kg in favor of MICT, to 0.35 kg in favor of IT. There were limited data reporting relative changes in lean mass, with only 3 studies directly comparing MICT vs IT. Pooling of these data revealed a moderate, but statistically non-significant, magnitude of effect (-0.98%) favoring MICT. However, due to the lack of data, the confidence intervals around the point estimate were wide (-3.39% to 1.43%), and Hedge's g values indicated a trivial standardized mean difference (0.17) with similarly wide interval estimates (-0.69 to 0.35). From a practical standpoint, these findings collectively suggest there may not be a meaningful difference between MICT and IT on absolute changes in lean mass.

Compared to non-exercising controls, our findings indicate trivial standardized effects for improvements in lean mass for both conditions (IT, Hedge's g = 0.13 [95%CI = 0.04 to 0.22]; MICT, Hedge's g = 0.07 [95%CI = -0.01 to 0.16]). IT showed absolute raw increases of 0.11 kg whereas MICT showed increases of 0.07, though for both the lower bounds of the interval estimates included zero and the upper bounds did not reach particularly meaningful values. These data collectively suggest that neither MICT nor IT meaningfully affect lean mass under the methods employed across studies, and call into question the claim that endurance-based exercise is a viable interventional strategy to promote muscle hypertrophy.

Exercise Adherence and Dropouts

Adherence was essentially identical between conditions, with both groups completing ~90% of sessions.; dropouts were also similar and relatively low at ~13-17%. It has been argued that the intensity of effort of exercise influences core affective response (49), and that this is predictive of future intentions and behavior in relation to exercise (50). However, a recent systematic review suggests that affective response may only differ trivially between IT and MICT, and that enjoyment responses may demonstrate a small effect in favor of IT (51). Despite varying speculative theories regarding the intensity of effort during exercise, its impact on affect or enjoyment, and subsequent behaviors, the results here suggest that adherence to IT and MICT is largely similar and relatively high at least over the duration of the studies and under the conditions in which the interventions were employed. Indeed, it should be noted that exercise sessions in the included studies were carried out with the aid of programming from the respective research teams and generally performed under direct supervision. It is well-established that programming and supervision have positive effects on exercise adherence (52). Thus, our findings in this regard cannot necessarily be extrapolated to self-directed exercise programs. Given the high interindividual variability observed in the psychological response to endurance exercise (53), it would seem that allowing for choice of training intensity would likely help to improve long-term adherence. Future research should endeavor to test this hypothesis under ecologically valid conditions.

Adverse Events

Of the studies reporting adverse events, there was essentially no difference between IT and MICT. On the surface, this would seem to suggest that both conditions are similarly safe in the populations studied. However, most studies failed to report incidences of adverse events. Furthermore, some studies lacked clarity as to whether there was a comprehensive attempt to record all possible adverse events associated with the training intervention. Thus, data on the topic is somewhat limited, precluding the ability to draw strong inferences regarding the safety between protocols.

A recent meta-analysis that examined the effects of supervised IT in patients with cardiovascular disease reported only 5 associated adverse cardiovascular events in ~17,000 training sessions: 1 major cardiovascular event, 1 minor cardiovascular, and 3 incidences of musculoskeletal issues. Although these findings appear to indicate that IT is generally safe, even in diseased populations, results may be confounded by underreporting of adverse events in individual studies and perhaps also sampling bias for the types of individuals likely to participate in such studies. Researchers are thus encouraged to track and disclose the occurrence of such incidences in future studies on HIIT and MICT so we can achieve a greater understanding of the risks associated with each strategy.

Inter-individual Response Variation

Variance of treatment responses to IT and MICT has been relatively underexplored despite numerous studies purporting that there may be inter-individual response variation to IT and MICT for a range of outcomes (17-19). Indeed, some have argued that such variation may mask differences between IT and MICT for fat loss (20). Evidence from the HERITAGE Family Study would genetically support this speculation given that a putative dominant locus accounting for 31% of variance in fat mass changes was found (54). However, we found no evidence of 'true' inter-individual variability in responses to either IT or MICT. This is in agreement with findings from a recent meta-analysis of aerobic exercise in overweight and obese children and adolescents on fat loss (16). Given our finding, and the relatively low heterogeneity across the main models for outcomes, the majority of apparent differences in study level results and apparent 'response heterogeneity' are likely attributable to sampling variance and random within-subject variability.

Limitations

The present meta-analysis has several limitations that must be taken into account when attempting to draw practical inferences on the effects of IT vs MICT on measures of body composition. First and foremost, only two studies prescribed dietary energy restriction for the interventional protocol. Thus, it is not clear whether one exercise strategy may be superior to another when combined with a nutritional intervention. Second, only one study supplemented the exercise intervention with a resistance training component. It is possible that differences in intensity and duration between IT and MICT protocols might alter responses when combined with resistance training. Although recent evidence questions whether there is an interference effect from concurrent training, at least for hypertrophy (55), the specific roles of endurance exercise intensity and duration upon fat mass under these conditions have yet to be elucidated. Third, very few studies involved trained athletes, and the vast majority of subjects would be considered overweight/obese. Thus, it remains to be determined how differences in endurance exercise intensity may affect body composition outcomes in lean and athletic populations. Moreover, the majority of included studies examined outcomes in younger to middle-aged adults, limiting our ability to draw conclusions about the effects of IT and MICT on older populations. Finally, our analysis is specific to body composition changes and does not take into account other potential effects of the different interventional exercise strategies. Some evidence indicates that higher intensities of exercise may confer superior health-related benefits such as improvements in glucose control, blood pressure, vascular function, and cardiorespiratory fitness (56). Thus, the use of a given endurance exercise strategy should consider individual goals in combination with abilities and preferences.

Conclusions

Our findings provide compelling evidence that the intensity of effort during endurance exercise has minimal influence on longitudinal changes in fat mass and lean mass. From a practical standpoint, this implies that individuals can choose the intensity of effort that best suits their needs and lifestyle. As a general rule, there is an efficiency/effort tradeoff along the intensity spectrum whereby IT requires less time but more effort than

MICT to promote alterations in body composition. Given that exercise adherence is of paramount concern, personal preference thus should guide prescription.

Our findings also indicate that structured exercise only has minor effects on fat loss regardless of intensity when performed at relatively modest doses; the amount of exercise required to achieve practically meaningful changes in this outcome seems to be unrealistic for most individuals. It is much easier to create an energy deficit from dietary restriction, which, therefore, should be the focus of weight loss interventions. However, exercise may help to preserve lean mass and functional performance during periods of energy restriction (57), as well as facilitate sustenance of weight loss in combination with a dietary intervention (58). Thus, it should be considered as an important supplement to nutritional approaches for those who endeavor to alter their body composition.

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Data and Supplementary Material Accessibility

All materials, data, and code are available on the Open Science Framework project page for this study https://osf.io/6karz/

Author contributions

BJS conceived of the study, designed the methods, and conducted the quality assessment; JS assisted in the methods design and carried out statistical analyses; JG conducted the quality assessment; DP, AR and MCM carried out the search; DV, HZ and BM coded the studies; all authors were meaningfully involved in interpreting data, and drafting and critically revising the manuscript for intellectually important content.

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