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Etiology and Pathophysiology

A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity

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Summary

Interval training (including high-intensity interval training [HIIT] and sprint interval training [SIT]) is promoted in both scientific and lay media as being a superior and time-efficient method for fat loss compared with traditional moderate-intensity continuous training (MICT). We evaluated the efficacy of HIIT/SIT when directly compared with MICT for the modulation of body adiposity. Databases were searched to 31 August 2016 for studies with exercise training interventions with minimum 4-week duration. Meta-analyses were conducted for within-group and between-group comparisons for total body fat percentage (%) and fat mass (kg). To investigate heterogeneity, we conducted sensitivity and meta-regression analyses. Of the 6,074 studies netted, 31 were included. Within-group analyses demonstrated reductions in total body fat (%) (HIIT/SIT: −1.26 [95% CI: −1.80; −0.72] and MICT: −1.48 [95% CI: −1.89; −1.06]) and fat mass (kg) (HIIT/SIT: −1.38 [95% CI: −1.99; −0.77] and MICT: −0.91 [95% CI: −1.45; −0.37]). There were no differences between HIIT/SIT and MICT for any body fat outcome. Analyses comparing MICT with HIIT/SIT protocols of lower time commitment and/or energy expenditure tended to favour MICT for total body fat reduction ($p = 0.09$). HIIT/SIT appears to provide similar benefits to MICT for body fat reduction, although not necessarily in a more time-efficient manner. However, neither short-term HIIT/SIT nor MICT produced clinically meaningful reductions in body fat.

Keywords: exercise, fat loss, high-intensity interval training, sprint interval training.

Abbreviations: BIA, bioelectrical impedance analysis; BMI, body mass index; CI, confidence interval; DEXA, dual-energy X-ray absorptiometry; EPOC, excess post-exercise oxygen consumption; ES, effect size; FFA, free fatty acid; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; MRI, magnetic resonance imaging; SIT, sprint interval training; VAT, visceral adipose tissue.

Introduction

Exercise is an integral component of obesity management. While exercise alone results in small weight losses, the combination of diet and exercise elicits the greatest magnitude of weight reduction for lifestyle therapy (1). Moreover, exercise alone improves cardiometabolic disease risk factors (1), and recent evidence demonstrates that aerobic exercise independently reduces visceral adipose tissue (VAT) (2–4). As such, the types and doses (specifically the mode, frequency, duration and intensity) of exercise which are the most effective for reducing adiposity need to be communicated to the general population, in addition to facilitating the adoption and maintenance of habitual exercise. While evidence suggests that aerobic-type exercise is effective for abdominal fat reduction (5), the nature of aerobic exercise for optimal fat loss remains debated.

The majority of exercise recommendations for the management of obesity promote high volumes of exercise (6–8). For instance, 150–250 min week^{-1} (6), and up to 60 min d^{-1} (7,8), of moderate-intensity aerobic exercise is advocated for weight gain prevention or modest weight reduction (2–3 kg) by the American College of Sports Medicine. For greater weight loss (5–7.5 kg), >420 min week^{-1} of moderate-intensity aerobic exercise is recommended (>60 min d^{-1}) (6). However, epidemiological data show that the majority of the adult population fails to meet the recommended physical activity guidelines (9), which are even lower in volume (and therefore time commitment) than those promoted for the management of obesity (10,11). A primary reason cited for failure to regularly exercise is a perceived lack of time (12), and it is therefore important to establish the efficacy of time-efficient doses of exercise to reduce the health risks associated with obesity.

Given both the need to enhance adoption and participation in regular exercise, and the evidence demonstrating the benefits of aerobic exercise in doses below current recommendations, there has been increasing interest in the utility of 'interval training' as an exercise strategy to improve health. Interval training involves a burst or repeated bursts of higher-intensity exercise interspersed with recovery bouts. The health benefits of interval training have been reviewed in detail elsewhere (13–16). These studies clearly show that compared with traditional moderate-intensity continuous training (MICT), interval training is a potent and time-efficient strategy for eliciting superior improvements in aerobic fitness (13,14,16) and ventricular and endothelial function in patients with cardiovascular disease (15,17) and leads to greater or comparable improvements in insulin sensitivity (16) and blood pressure (18).

Interval training is regularly promoted in the scientific (19) and lay media as being a superior and time-efficient method for fat loss. However, research investigating the efficacy of interval training on body composition is equivocal, with large variations in study design, few studies that directly compare interval training protocols with MICT and few that used a valid assessment of VAT. It is therefore unclear whether interval training is a suitable alternative or substitute for the more time-consuming MICT, and which of the two approaches is best for fat loss. Clarifying these issues is important, because failure to achieve desired lifestyle programme outcomes is strongly associated with programme dropout and feelings of guilt and failure (20).

The aim of this study, therefore, was to conduct a systematic review with meta-analysis of the pooled data from studies that have directly compared MICT with high-intensity interval training (HIIT) or sprint interval training (SIT) for the modulation of body adiposity in humans. Such an analysis is ideal for the comparison of these exercise modalities as the individual reports in this area tend to have low sample sizes and may lack sufficient power to detect between-group differences. We hypothesized that HIIT/SIT would produce a superior reduction in fat compared with MICT.

Methods

The results of this systematic review are presented according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement (21).

Search strategy

English-language searches of the electronic databases PubMed and Google Scholar were conducted from inception to 31 August 2016 by one researcher (S.K.). These databases were selected as complementary databases for both sensitivity and specificity regarding their ability to detect relevant articles (22,23). Keywords included 'interval training', 'intermittent training', 'high intensity', 'sprint interval training', 'aerobic interval training', 'continuous training', 'moderate-intensity continuous exercise' and 'HIIT', and 'body fat', 'adiposity', 'body composition', 'abdominal fat', 'visceral fat' and 'adipose tissue'. Reference lists of all retrieved papers were manually searched for potentially eligible papers. Manuscripts published in all languages were included. Studies were excluded based on file type: book sections, theses, film/broadcasts, opinion articles, observational studies and abstracts without adequate data or reviews (Fig. 1).

Inclusion and exclusion criteria Participants, Interventions, Comparators, Outcomes (PICO)

Participants were not restricted by age or sex. Included studies directly compared HIIT or SIT with MICT (for definition of interventions, see succeeding texts) and assessed fat change by methods that infer total or regional percentage fat or total or regional fat mass. Studies that compared either HIIT or SIT with a control group were not included as the primary aim was to directly compare interval training with MICT. In studies that employed two interval training protocols, the interval regimen with the largest volume was included for comparison with MICT. Given the well-established weak association between body

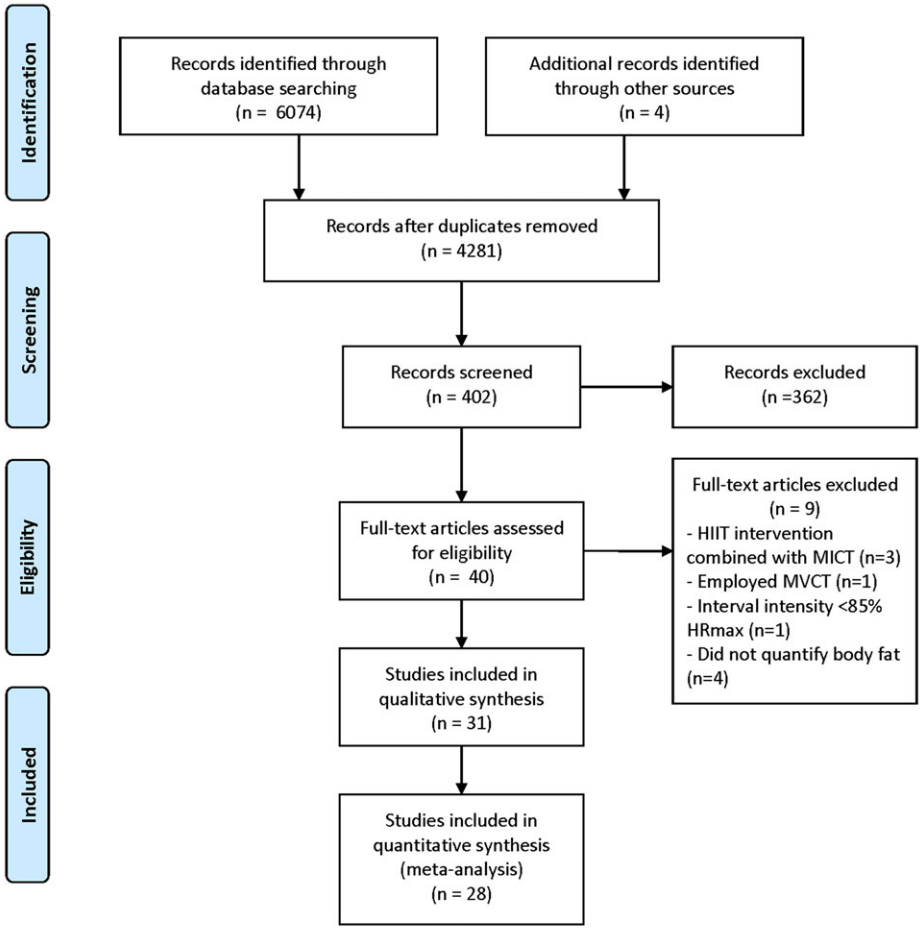

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (2009) flow diagram of outcomes of review. HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; MVCT, moderate-vigorous continuous training. [Colour figure can be viewed at wileyonlinelibrary.com]

mass index (BMI), adiposity and chronic disease (24), we did not include studies that only reported weight or BMI as an outcome. Studies with a minimum exercise training duration of 4 weeks were included.

Types of interval training: definitions

Interval training can vary in the number and intensity of intervals, the time and nature (active or passive) of recovery periods and therefore the work: recovery schedule. The definitions used in the present review, and described hereafter, are based on a recently proposed classification scheme for interval training (25), which enables differentiation between protocols and may explain the differences in outcomes observed in studies of interval training (26).

Sprint interval training. This is defined as 'all-out' sprints (>100% of the maximal rate, VO_{2max}) interspersed with recovery periods. These protocols typically employ short bursts (8–30 s) of supra-maximal sprint efforts requiring a relatively large anaerobic contribution, which are approximately equivalent to those undertaken in running events of ~100–200 m or during explosive intermittent bursts during team sports. SIT is commonly employed in young and/or healthy populations and has been associated with a range of health benefits including large improvements in cardiorespiratory fitness (13). However, the safety and utility of SIT in clinical populations are yet to be established.

High-intensity interval training. This classifies protocols targeting intensities between 80% and 100% peak heart rate or aerobic capacity. HIIT is sometimes called aerobic interval training, and protocols typically employ bursts of activity lasting between 60 and 240 s, which are within the aerobic capacity of the individual (sub-maximal), but extremely strenuous. For most individuals, this may equate with an intensity that, if undertaken without rest, could otherwise be sustained for ~5–10 min before fatigue. The intermittent nature allows enough recovery for multiples of these efforts to be accumulated.

Moderate-intensity continuous training. This describes 'traditional' exercise protocols performed continuously at a steady state for a set duration (usually 20–60 min). Moderate-intensity activity is defined as an intensity that elicits a heart rate response of 55–69% HR_{max} or elevates the rate of oxygen consumption to 40–59% of VO_{2max} (27).

Data extraction

Outcome measures used were percentage total and regional body fat (%) and total or regional fat mass (kg). Data on participant characteristics, HIIT/SIT and MICT interventions and body adiposity outcomes were extracted independently by two researchers (S. K. and N. J.) with disagreements resolved by a third researcher (J. C.). In cases where journal articles contained insufficient information, attempts were made to contact authors to obtain missing details.

In order to examine the relationships between exercise-induced energy expenditure and change in body adiposity, we estimated exercise session and/or total exercise intervention energy expenditure, where possible. Energy expenditure values were included if reported in the manuscript or were calculated using reported data for group mean VO_{2max} and protocol intensity/duration assuming a 21 kJ min^{-1} energy expenditure during exercise at a VO_2 of 1 L min^{-1}. Energy expenditures for Wingate/Sprint protocols were not calculated given the high anaerobic contribution.

Meta-analyses

All analyses were conducted using STATA v12.1 (StataCorp. 2012. Stata Statistical Software, Release 12; College Station, TX, USA). Meta-analyses were conducted for the individual effects of HIIT/SIT and MICT on body fat percentage and total body fat (kg). For these secondary meta-analyses, pre-means and post-means and standard deviations for each group were collected. Initially, a within-group effect size (ES) was calculated to estimate change from baseline for each group. Given that this within-group analysis was based on pre-mean and post-mean data provided in each study, and in order to incorporate a correction for paired data, we presumed a correlation of 0.7 measured within each comparison group. We examined a range of correlations between 0.5 and 0.9 and determined 0.7 to be the most appropriate and conservative approach. All analyses were performed with different correlation assumptions between 0.5 and 0.9, and the overall results were not substantially altered.

For our primary analysis, a between-group meta-analysis was conducted by pooling data for HIIT and SIT interventions, compared with MICT, with subgroup analyses for studies that employed HIIT/SIT protocols in which the exercise sessions were lower in time commitment and/or energy expenditure, and those which reported being 'matched' for energy expenditure/workload. For the ES between groups, post-test mean values or change scores, were used to analyse the effect of HIIT/SIT compared with MICT. This post-mean approach was preferred, rather than comparison between effects, given this review included only randomized studies, and theoretically any difference post-intervention is related to the intervention. This strategy was based upon guidelines from the Cochrane Handbook for Systematic Reviews of Interventions (28). Weighted unstandardized ESs and their 95% confidence interval (95% CI) were calculated using both fixed and random effect meta-analysis with inverse of variance. Heterogeneity was calculated by I^2 statistic, which measures the degree of inconsistency between studies and indicates the proportion of variability between studies that is not due to chance, i.e. occasioned by heterogeneity between studies. Values of <25%, 50% and 75% were considered to indicate low, moderate and high heterogeneity, respectively.

Publication bias was visually assessed by funnel plots and Begg's test, plotting the ES of each trial against its standard error. To add robustness to our findings, we conducted a series of sensitivity analyses by (i) analysing the individual influence of each study by deleting from the model each study once in order to analyse the influence of each study on the overall results; (ii) conducting subgroup analyses according to the type of comparison group (HIIT or SIT), sex, intervention duration (<12 vs ≥12 weeks), BMI, age (<30 vs ≥30 years) and the quality score of the paper (based on tertiles 'low, middle and high'); and (iii) estimating the potential impact that a new study would have on our results by displaying statistical contours. These contours define regions based on ES and standard error in which a new study would have to be located to either change the statistical significance or affect the extent of heterogeneity of the meta-analysis (28).

Study quality

Study quality was assessed by two researchers (S.K. and N.J.) using a modified Downs and Black checklist (29). Items included the adequate reporting of the following: hypotheses, outcomes, interventions, adverse events, participant characteristics (on the basis of clearly stated inclusion and exclusion criteria), descriptions of patients lost to follow-up (studies with >10% dropout without characteristics reported scored 0), assessment method accuracy, statistical methods, blinding and randomization procedures. The scale was modified to include criteria for estimation of exercise energy expenditure, monitoring and reporting of habitual energy expenditure and diet, the supervision of exercise sessions and whether adherence to the exercise interventions was reported. If an item was unable to be determined, it was scored as zero. The highest possible score for quality was 21.

Results

The initial search netted 6,074 studies that were appraised by title and abstract. Three studies included MICT within the HIIT protocol and were excluded from this review as it is difficult to delineate the efficacy of HIIT given the mixed-mode nature of these protocols (30–32). The corresponding authors for four studies were contacted in an attempt to gain values for exercise session energy expenditure; however, none responded (33–35). Two studies did not provide sufficient data to be included in the qualitative review (36,37), and one only reported the outcome of android fat (38). Therefore, a total of 31 papers met inclusion criteria, with 28 papers included for quantitative analyses, providing 35 estimates for meta-analysis (25 for body fat [%] and 10 for fat mass [kg]) (Fig. 1).

Participant characteristics

Participant characteristics are summarized in Table 1. When combined, 837 individuals (402 women, 402 men and 33 not reported) participated in the included trials. Mean age ranged from 10.4 to 65 years. Most studies recruited untrained healthy young adults (33,35,39–41,47,52,56–58,60,61) (n = 12), or adults with overweight/obesity (36–38,44,45,48–51,53–55,62) (n = 13), with three studies recruiting children and/or adolescents (42,43,46), one study recruiting adults with metabolic syndrome (59) and one study recruiting for colorectal cancer survivors (63), and one for women with mild hypertension (34) (Table 1).

Intervention characteristics

Details of the exercise intervention are summarized in Table 2. By our definitions (25), 17 of the 31 included studies employed an HIIT intervention (37,39,41,43–46,49,50,52,54,56,57,59–61,63), and 14 employed SIT (33–36,38,40,42,48,51,53,55,58,61,62). Cycling ergometry was the most common mode selected for training (n = 16) (35,36,38,40,47,48,51–53,55–58,60,62,63), followed by walking/running (n = 12) (33,37,39,41–46,49,54,61), with one study employing swimming (34), one employing boxing for the HIIT protocol and walking for MICT (50) and one offering either treadmill or cycle ergometer depending upon orthopaedic limitations (59). Intervention duration ranged from 4 to 16 weeks with 12 weeks being the most common (n = 13) (Table 2).

Details of the methods used for assessment of body fat are summarized in Table 3. Some studies used multiple methods. Only two of the included studies employed a gold standard measurement of VAT via magnetic resonance imaging (60) or computed tomography (54). Bioelectrical impedance analysis was used to infer total body fat (%) in five studies (43,44,52,54,60), and skinfold measures were used in five studies (35,42,46,50,57). Densitometry was employed in three studies via hydrodensitometry (39) and air displacement plethysmography (33,58). Eighteen studies used dual-energy X-ray absorptiometry for the quantification of total, and/or android, trunk and gynoid body composition (34,36–38,40,41,45,48,50,51,53,55,56,59,61–63).

The level of control for habitual dietary intake and habitual physical activity and sedentary behaviour are reported in Table 2. In an attempt to account for potentially confounding changes in habitual physical activity and diet, nine studies (26%) (36,38,40,48,54–56,59,60) monitored and reported habitual diet, and 13 studies (43%) monitored and reported habitual activity energy expenditure (36,38,40,42,43,48,49,53–55,57,59,60) (Tables 2 and S1).

Methodological quality

Assessment of the study quality is available in Table S1. Quality was assessed as a score out of 21 with a mean score of 13.7 ± 2.7 (minimum 9, maximum 20). All included studies specified their main outcomes, main findings, interventions, variability estimates and statistical tests. No studies blinded participants to exercise intervention and six blinded assessors to group allocation. Thirteen studies (43%) attempted to quantify the energy expenditure of the exercise bout and/or total exercise intervention, and adherence or compliance was reported in 20 studies (65%). Only five studies reported the time frame of recruitment, and 15 studies adequately reported adverse events (Table S1).

Meta-analyses

The within-group analyses of HIIT/SIT and MICT pre–post effects on body adiposity outcomes are presented in Figs S1 and S2, respectively. Both HIIT/SIT and MICT resulted in decreases in total body fat (%) and total fat mass (kg). The results of pre–post effect showed an average decrease in total body fat (%) with HIIT/SIT of −1.26 (95% CI: −1.80; −0.72; I^2 = 45.1%) and in fat mass (kg) of −1.38 (95% CI: −1.99; −0.77; I^2 = 0.0%) (Fig. S1). Similar decreases were observed in MICT for total body fat percentage (%) (ES: −1.48 [95% CI: −1.89 to −1.06], I^2 = 8.6%) and for total fat mass (kg) (ES: −0.91 [95% CI: −1.45 to −0.37], I^2 = 0.0%) (Fig. S2).

Table 1 Participant characteristics

Reference	Subjects*	Male/female (%)	Age (year)	BMI (kg/m^2)	Other population characteristics
Thomas *et al.* (39)	29	38/62	18–32	NR	Healthy, untrained but active young adults (aged 18–32 years)
Schjerve *et al.* (37)	27	22/78	HIIT: 46.9 (8.2) MICT: 44.4 (7.6)	HIIT: 36.6 (4.5) MICT: 36.7 (5.1)	Adults with obesity
Trapp *et al.* (40)	30	0/100	20.2 (7.7)	23.2 (7.7)	Healthy, untrained young women
Wallman *et al.* (38)	16	NR	SIT: 40.9 (11.7) MICT: 44.8 (16.8)	SIT: 31.4 (2.6) MICT: 30.1 (2.6)	Inactive adults with overweight/obesity
Macpherson *et al.* (33)	20	40/60	24.0 (3.0)	NR	Healthy, recreationally active university students
Nybo *et al.* (41)	17	100/0	HIIT: 37.0 (8.5) MICT: 31.0 (6.0)	NR	Healthy, untrained men
Buchan *et al.* (42)	34	79/21	SIT: 16.7 (0.1) MICT: 16.2 (0.1)	NR	Adolescents (school years 5 and 6)
Corte de Araujo *et al.* (43)	30	30/70	HIIT: 10.4 (0.9) MICT: 10.7 (0.7)	HIIT: 32.0 (3.0) MICT: 30.0 (4.0)	Children (8–12 years) with obesity
Eimarieskandari *et al.* (44)	14	0/100	22.1 (0.5)	HIIT: 29.2 (0.8) MICT: 30.7 (2.3)	Young adults with obesity
Sijie *et al.* (45)	33	0/100	HIIT: 19.8 (1.0) MICT: 19.3 (0.7)	HIIT: 27.7 (1.9) MICT: 28.3 (2.0)	Young (19–20 years) women with overweight/obesity
Koubaa *et al.* (46)	29	100/0	13.0 (8.0)	HIIT: 30.2 (3.6) MICT: 30.8 (2.9)	Adolescents boys with obesity
Shepherd *et al.* (47)	16	100/0	SIT: 22.0 (2.8) MICT: 21.0 (2.8)	SIT: 24.8 (2.3) MICT: 22.6 (4.5)	Healthy, inactive adults
Keating *et al.* (48)	22	23/77	42.8 (8.6)	28.3 (0.3)	Inactive adults with overweight
Lunt *et al.* (49)	33	27/73	HIIT: 48.2 (5.6) MICT: 46.3 (5.4)	HIIT: 32.1 (3.1) MICT: 32.7 (3.4)	Inactive adults with overweight/obesity
Nalcakan *et al.* (35)	15	100/0	21.7 (2.2)	25.0 (2.1)	Healthy, young recreationally active university students
Mohr *et al.* (34)	42	0/100	SIT: 44.0 (9.1) MICT: 46.0 (9.1)	NR	Premenopausal, mild hypertension
Saski *et al.* (60)	24	100/0	NR	23.9 (2.4)	Healthy
Cocks *et al.* (62)	16	100/0	25.0 (2.8)	34.8 (0.9)	Inactive young men with obesity
Cheema *et al.* (50)	12	58/42	39.0 (17.0)	31.4 (4.4)	Inactive adults with central obesity
Devin *et al.* (63)	35	100/0	61.5 (10.9)	26.9 (4.3)	Colorectal cancer survivors
Elmer *et al.* (61)	12	100/0	HIIT: 21.4 (1.1) MICT: 21.8 (2.1)	HIIT: 24.7 (2.9) MICT: 27.1 (4.8)	Healthy sedentary or inactive adults
Fisher *et al.* (51)	23	100/0	20.0 (1.5)	29.5 (3.3)	Inactive young men with overweight/obesity
Martins *et al.* (36)	17[#]	NR[#]	34.8 (8.8)	33.3 (2.9)	Inactive adults with obesity
Shepherd *et al.* (52)	90	33/67	42.0 (11.0)	27.7 (4.8)	Healthy, inactive adults
Sim *et al.* (53)	12	100/0	31.8 (8.0)	27.2 (1.3)	Inactive adult men with overweight/obesity
Zhang *et al.* (54)	24	0/100	HIIT: 21.0 (1.0) MICT: 20.6 (1.2)	HIIT: 25.8 (2.7) MICT: 26.0 (1.6)	Chinese ethnicity, inactive with overweight/obesity
Higgins *et al.* (55)	52	100/0	20.4 (1.5)	30.3 (4.5)	Inactive women with overweight/obesity
Hwang *et al.* (56)	29	41/59	65 (7.1)	HIIT: 28.0 (4.3) MICT: 28.7 (3.7)	Inactive healthy older adults
Panissa *et al.* (57)	23	0/100	28.4 (12.5)	HIIT: 25.9 (4.1) MICT: 23.3 (2.3)	Inactive healthy women
Gillen *et al.* (58)	18	0/100	27.0 (8.0)	26.0 (6.0)	Inactive men
Ramos *et al.* (59)	43	63/37	HIIT: 56.0 (10.0) MICT: 57.0 (9.0)	HIIT: 33.0 (5.0) MICT: 32.0 (6.0)	Adults with metabolic syndrome

*Number included in MICT vs HIIT for body composition analysis.

[#]n = 17 for body composition analysis in HIIT vs MICT – sex of those who were not included in body composition analysis were not reported. Values reported as mean (SD); in instances where results presented as mean (SEM), SEM was converted to SD using SD = SEM × Sqrt^n.

HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; NR, not reported; SD, standard deviation; SEM, standard error of the mean; SIT, sprint interval training.

Table 2 Details of exercise intervention protocols of included studies for HIIT/SIT and MICT

Reference	HIIT/SIT protocol	MICT protocol	Intervention duration (weeks)	Control of diet (D) and habitual activity (PA)
Thomas *et al.* (39)	n = 15 8 × 1 min at 90% MHR with 3-min walk, 3/7	n = 14 Four mile running at 75% MHR, 3/7	12	NR
Schjerve *et al.* (37)	n = 14 4 × 4-min running at 85–95% HR_{max} with 3 min R at 50–60% HR_{max}, 3/7	n = 13 47-min walking at 60–70% HR_{max}, 3/7	12	D: NR PA: not controlled
Trapp *et al.* (40)	n = 15 A maximum of 60 × 8-s all-out sprints on cycle ergometer with 12-s R (slow pedal between 20 and 30 rpm) Progressed to 20-min cycling per session, 3/7	n = 15 10- to 40-min cycling at 60% VO_{2peak}Progressed to 40-min cycling per session, 3/7	15	Instruction to maintain normal D and PA. D: records pre-study and post-study PA: NR
Wallman *et al.* (38)	n = 8 Dietary education plus:10 × 60-s cycling at 90–120% VO_{2peak} with 2-min R at 30–45% VO_{2peak}, 4/7	n = 8 Dietary education plus:cycling at 50% VO_{2peak} for duration to match energy expenditure of matched HIIT partner, 4/7	8	D: 1-h education session D: records pre-study and post-study PA: monitored
Macpherson *et al.* (33)	n = 10 4–6 × 30-s all-out run sprints on manually driven treadmill with 4-min R, 3/7	n = 10 30- to 60-min running at 65% VO_{2peak}, 3/7	6	Instruction to maintain normal D and PA
Nybo *et al.* (41)	n = 8 20-min of interval running 5 × 2 min at >95% HR_{max} by end of 2-min interval, 3/7 (mean 2 [2.8]/7 reported)	n = 9 60-min running at 80% HR_{max}, 3/7 (mean 2.5 [0.6]/ 7 reported)	12	Instruction to maintain normal D PA: NR
Buchan *et al.* (42)	n = 17 4–6 × 30-s maximal run sprints within 20-m distance with 20–30-s R, 3/7	n = 17 20-min running at 70% VO_{2max}, 3/7	7	Instruction to maintain normal D and PA D: Food frequency data collected
Corte de Araujo *et al.* (43)	n = 15 3–6 × 60-s treadmill walking/running at 100% HR_{peak} with 3-min R at 50% 2/7	n = 15 30- to 60-min treadmill walking/running at 80% HR_{peak}, 2/7	12	D: Food intake data collected PA: NR
Eimarieskandari *et al.* (44)	n = 7 4 × 4 min on treadmill at 85–95% HR_{peak} with 3-min R at 50–70% HR_{peak} 3/7	n = 7 41-min on treadmill at 50–70% HR_{peak}, 3/7	8	Instruction to maintain normal D D: records pre-study and post-study PA: NR
Sijie *et al.* (45)	n = 17 ~ 42 min of intervals: 5 × 3-min running at 85% VO_{2max} with 3-min R at 50% VO_{2max}, 5/7	n = 16 40-min walking/jogging at 50% VO_{2max}, 5/7	12	Instruction to maintain normal D and PA
Koubaa *et al.* (46)	n = 14 2 min at 80–90% vVO_{2max} with 1-min R, 3/7	n = 15 30–40 min at 60–70% vVO_{2max}, 3/7	12	NR
Shepherd *et al.* (47)	n = 8 4–6 × 30-s Wingate sprints against a load equivalent to 0.075 kg/kg of body mass with 4.5-min R at 30W, 3/7	n = 8 50- to 60-min cycling at ~65% VO_{2peak}, 5/7	6	Instruction to maintain normal D and PA D: 3-d weighed D records pre-intervention and post-intervention
Keating *et al.* (48)	n = 13 6 × 60-s cycling at power to elicit 120% VO_{2peak} with 120-s R at 30W, 3/7	n = 13 45-min cycling at 65% VO_{2peak}, 3/7	12	Instruction to maintain normal D and PA D: records pre-study and post-study PA: monitored (accelerometry) pre-study and post-study

(*Continues*)

Table 2 (Continued)

Reference	HIIT/SIT protocol	MICT protocol	Intervention duration (weeks)	Control of diet (D) and habitual activity (PA)
Lunt *et al.* (49)	*n* = 16 4 × 4-min fast walking or jogging at 85–95% HR_{max} with 3-min R,10-min warm up and 5-min cool down 40 min per session, 3/7	*n* = 17 33-min walking at 65–75% HR_{max}, 10-min warm up and 5-min cool down 48 min per session, 3/7	12	D: records pre-intervention and post-intervention PA: monitored pre-intervention and post-intervention via pedometer
Nalcakan *et al.* (35)	*n* = 8 4–6 × 30-s Wingate sprints with 4.5-min R, 3/7	*n* = 7 30- to 50-min cycling at 60% VO_{2max}, 3/7	7	Instruction to maintain normal D and PA
Mohr *et al.* (34)	*n* = 21 6–10 × 30-s all-out freestyle swimming with 2-min R, 3/7	*n* = 21 60-min freestyle swimming. Encouraged to swim as far as possible each session, 3/7	15	Not controlled
Saski *et al.* (60)	*n* = 12 10 × 60-s cycling at 85% VO_{2max} with 30-s R, 3/7	*n* = 12 22-min cycling at 45% VO_{2max}, 3/7	4	Instruction to maintain normal D and PA D: history for 1 week PA: accelerometry for 1 week
Cocks *et al.* (62)	*n* = 8 2-min warm up at 50W then 4–7 × 30-s cycle sprints at 200% W_{max}, 3/7	*n* = 8 40- to 60-min cycling at ~65% VO_{2peak}, 5/7	4	NR
Cheema *et al.* (50)	*n* = 6 5-min warm up, skipping at self-selected intensity followed by 2 min of boxing drills at 15–17/20 RPE with 1-min R (standing/pacing) for 50 min, Mean HR 86–89% HR_{max}, 4/7	*n* = 6 5-min warm up, 45-min brisk walking, unsupervised (home-based), Mean HR 64–77% HR_{max}, 4/7	12	NR
Devin *et al.* (63)	*n* = 21 4 × 4-min cycling at 85–95% HR_{peak} with 3-min R at 50–70% HR_{peak}, 38 min per session, 3/7	*n* = 14 50-min cycling at 50–70% HR_{peak}, 3/7	4	Instruction to maintain normal D and PA PA: quantified via questionnaire pre-intervention and post-intervention
Elmer *et al.* (61)	*n* = 6 3-min warm up and cool down at 60% vVO_{2max} followed by 12 × 1 min at 90–110% vVO_{2max} and 1-min at 50% vVO_{2max} on treadmill, 30 min, 3/7	*n* = 6 30-min at 70–80% vVO_{2max} on treadmill 3/7	8	Instruction to maintain normal D and PA
Fisher *et al.* (51)	*n* = 13 4 × 30-s at 85% of max anaerobic power with 4-min R at 15% of max anaerobic power with for 20 min, 3/7	*n* = 10 45- to 60-min continuous cycling at 55–65% VO_{2peak}, 5/7	6	NR
Martins *et al.* (36)	*n* = 6 8-s sprint (HR elevated to 85–90% HR_{max}) with 12-s R expending 1,050 kJ, 3/7	*n* = 6 Cycling at 70% HR_{max} Expending 1,050 kJ, 3/7	12	Instruction to maintain normal D and PA D: 3-d food diaries at baseline and in last week PA: Accelerometer worn for 7 d at baseline, weeks 6 and 12
Shepherd *et al.* (52)	*n* = 42 Gym-based exercise class15–60-s sprints on cycle ergometer at >90% HR_{max} with 45–120-s R active recovery 5-min cool down18–25 min per session, 3/7	*n* = 44 Gym-based exercise class 30- to 45-min cycling at 70% HR_{max} 3 supervised + 2 unsupervised sessions per week (total = 5/7)	10	D: 24-h food diaries taken to replicate pre-assessment–post-assessment intake preceding assessments
Sim *et al.* (53)	*n* = 10 Repeated bouts of 15-s on cycle ergometer at approximately 170% VO_{2peak} with 60-s active R at	*n* = 10 Cycling at 60% VO_{2peak} 30–45 min per session, 3/7	12	D: 48-h weighed food diaries pre-intervention and post-intervention

(*Continues*)

Table 2 (Continued)

Reference	HIIT/SIT protocol	MICT protocol	Intervention duration (weeks)	Control of diet (D) and habitual activity (PA)
	approximately 32% VO_{2peak} 30–45 min per session, 3/7			PA: accelerometry pre-intervention and post-intervention
Zhang *et al.* (54)	*n* = 12 4 × 4 min on treadmill at 85–95% HR_{peak} with 3-min R at 50–60% HR_{peak}, then a 7-min rest, 4/7	*n* = 12 33-min on treadmill at 60–70% HR_{peak}, 4/7	12	Pre-intervention and post-intervention D: diary recorded PA: diary recorded
Higgins *et al.* (55)	*n* = 23 5–7 × 30-s 'all-out' cycling sprints with 4-min active R equating to 2.5–3.5 min of near maximal effort interspersed with 16–28 min of recovery, 3/7, performed in group environment	*n* = 29 20- to 30-min cycling at 60–70% HRR, 3/7, performed in group environment	6	D: 3-d food record recorded pre-intervention and post-intervention with 24-h recall PA: Omnidirectional accelerometer worn for 3-d pre-intervention and post-intervention
Hwang *et al.* (56)	*n* = 15 4 × 4 min on all-extremity air-braked ergometer at 90% HR_{peak} with 3-min R at 70% HR_{peak}.5-min cool down at 65–75% HR_{peak}, 4/7	*n* = 14 32-min on all-extremity air-braked ergometer at 70% HR_{peak}, 4/7	8	Instruction to maintain normal D and PA D: not monitored PA: triaxial accelerometer worn for 4-d pre-intervention and post-intervention
Panissa *et al.* (57)	*n* = 11 15 × 60-s at 90% MHR on cycle ergometer with 30-s R at 60% MHR, 3/7	*n* = 12 29-min cycling at 70% MHR, 2/7	6	Instruction to maintain normal D and PA D: 3-d food record recorded pre-intervention and post-intervention
Gillen *et al.* (58)	*n* = 9 3 × 20-s 'all-out' cycling sprints against 0.06 kg/kg body mass (~500W) with 2-min recovery at 50W, 3/7	*n* = 9 45-min cycling at ~70% MHR (~110W), 3/7	12	NR
Ramos *et al.* (59)	*n* = 22 4 × 4 min at 85–95% HR_{peak} with 3-min R at 50–70% HR_{peak} 38 min per session, 3/7	*n* = 21 30-min at 60–70% HR_{peak}/ RPE 11–13, 30-min per session, 5/7	16	D: 3-d food record recorded pre-intervention and post-intervention PA: measured pre-intervention and post-intervention via accelerometer

Patient or population: All human participants included in trials comparing HIIT or SIT with MICT.
Intervention: HIIT – protocols targeting intensities between 80% and 100% peak heart rate or aerobic capacity interspersed with recovery periods – or SIT – 'all-out' sprints (>100% of the maximal rate, VO_{2max}) interspersed with recovery periods.
Comparison: MICT – continuous steady-state aerobic exercise that elicits a heart rate response of 55–69% HR_{max} or elevates the rate of oxygen consumption to 40–59% of VO_{2max}.
Outcome: Body adiposity (total or regional body fat percentage or fat mass).
Values reported as mean (SD); in instances where results presented as mean (SEM), SEM was converted to SD using SD = SEM × Sqrt^*n*.
D, diet; HIIT, high-intensity interval training; HR_{peak}, peak heart rate; MHR, maximal heart rate; MICT, moderate-intensity continuous training; NR, not reported; PA, physical activity; R, recovery; SD, standard deviation; SEM, standard error of the mean; SIT, sprint interval training; VO_{2max}, maximal oxygen consumption; VO_{2peak}, peak oxygen consumption; VT, ventilator threshold; W, watts; RPE, rating of perceived exertion; HRR, heart rate reserve.

Primary analysis

The between-group analyses for HIIT/SIT versus MICT are presented in Fig. 2. Overall, there were no differences between group for any outcome, with evidence of low heterogeneity for the meta-analysis of total body fat (I^2 = 6.5%) and total fat mass (I^2 = 0.0%). Subgroup analyses demonstrated that studies that employed HIIT/SIT protocols that were lower in time commitment and/or energy expenditure than MICT tended to favour MICT for total body fat reduction (p = 0.09). There were no significant differences between groups for studies that employed exercise protocols that were 'matched' for workload/or energy expenditure between HIIT/SIT and MICT (p = 0.40). There were no significant between-group differences in the subgroup analyses for fat mass (p = 0.56 and p = 0.38 for less time/less energy expenditure and 'matched' protocols, respectively) (Fig. 2A,B). The general

Table 3 Outcomes of intervention studies for change in body adiposity

Reference	Mode	Energy expenditure	Body composition assessment method	Pre, mean (SD)	Post, mean (SD)	Change score
Thomas *et al.* (39)	HIIT: *n* = 15 MICT: *n* = 14	*Per session:* HIIT and MICT: ~2,090 kJ per session *Total intervention:* HIIT and MICT: ~75,240 kJ ‡	Hydrodensitometry (total body fat, %)	HIIT: 22.5 (7.0)† MICT: 18.0 (7.0)†	HIIT: 18.5 (8.0)† MICT: 16.0 (8.0)†	NR
Schjerve *et al.* (37)	HIIT: *n* = 14 MICT: *n* = 13	*Per session:* HIIT: ~1,265 kJ per session‡ MICT: ~1,288 kJ per session‡ *Total intervention:* HIIT: ~45,540 kJ‡ MICT: ~46,368 kJ‡	DEXA (total body fat, %)	HIIT: 40.6 (6.0) MICT 43.6 (5.4)	NR	HIIT: −2.5%* MICT: −2.2%*
Trapp *et al.* (40)	SIT: *n* = 15 MICT: *n* = 15	*Per session:* SIT: 834.5 (43.8) kJ per session MICT: 809.7 (286.6) kJ per session *Total intervention:* SIT: 41.5 (3.1) MJ MICT: 36.3 (13.2) MJ	DEXA Trunk fat (kg)	SIT: 11.4 (7.7) MICT: 8.6 (5.0)	SIT: 10.0 (6.2)** MICT: 8.8 (4.6)	NR
			Total body fat (%)	SIT: 35.1 (10.5) MICT: 31.7 (11.6)	SIT: 32.4 (8.9) MICT: 32.3 (10.1)	SIT: −2.5 (3.2)** MICT: 0.4 (3.4)
			Central abdominal fat (kg)	NR	NR	SIT: −0.2 (0.3) MICT: 0.1 (0.3)
			Total fat (kg)	SIT: 22.2 (11.6) MICT: 18.4 (8.5)	SIT: 19.7 (10.1) MICT: 18.8 (2.1)	
Wallman *et al.* (38)	SIT: *n* = 8 MICT: *n* = 8	*Per session:* (pre-intervention–post-intervention) SIT: 131.6 (30.6)–165.2 (38.7) kJ per session MICT: 131.9 (30.7)–181.8 (34.9) kJ per session	DEXA (android fat mass, kg)	SIT: 3.8 (0.4) kg MICT: 3.7 (0.9) kg	SIT: 3.5 (0.5) kg* MICT: 3.6 (1.1) kg*	NR
Macpherson *et al.* (33)	SIT: *n* = 10 MICT: *n* = 10	NR	Whole-body densitometry via air displacement (BodPod®) (fat mass, kg)	SIT: 13.7 (4.9) MICT: 13.9 (5.5)	SIT: 12.0 (4.9)* MICT: 13.1 (5.5)*	SIT: −12.4%* MICT: −5.8%*
Nybo *et al.* (41)	HIIT: *n* = 8 MICT: *n* = 9	*Per session:* HIIT: ~679 kJ per session‡ MICT: ~2,974 kJ per session *Total intervention:* HIIT: ~24,444 kJ‡ MICT: ~107,064 kJ‡	DEXA (total body fat, %)	HIIT: 24.7 (4.2) MICT: 24.3 (4.8)	HIIT: 24.2 (4.8) MICT: 22.6 (5.1)*	NR
Buchan *et al.* (42)	SIT: *n* = 17 MICT: *n* = 17	*Total energy expenditure:* SIT: 3,792.1 kJ MICT: 18,433.8 kJ	Two site skinfold: triceps and calf (total body fat %)	SIT: 18.7 (7.7) MICT: 19.7 (8.6)	SIT: 19.2 (5.8) MICT: 17.6 (6.5)*	NR
Corte de Araujo *et al.* (43)	HIIT: *n* = 15 MICT: *n* = 15	*Per session:* HIIT: 351.1 (64.0)–709.3 (127.9) kJ per session	Bioelectrical impedance (fat mass, %)	HIIT: 38.0 (5.0) MICT: 37.0 (4.0)	HIIT: 37.0 (4.0) MICT: 36.0 (4.0)	NR

(*Continues*)

Table 3 (Continued)

Reference	Mode	Energy expenditure	Body composition assessment method	Pre, mean (SD)	Post, mean (SD)	Change score
		MICT: 1,120.7 (256.7)–2,241.3 (513.3) kJ per session *Total intervention:* HIIT: ~17,023 kJ‡ MICT: ~40,344 kJ‡				
Eimarieskandari *et al.* (44)	HIIT: *n* = 7 MICT: *n* = 7	'Work matched' *Per session:* HIIT: ~743 kJ per session‡ MICT: ~800 kJ per session *Total intervention:* HIIT: ~17,832 kJ‡ MICT: ~19,200 kJ‡	Bioelectrical impendence analysis (total body fat, %)	HIIT: 36.0 (0.6) MICT: 36.9 (1.2)	HIIT: 35.8 (0.7) MICT: 35.2 (1.3)**	NR
Sijie *et al.* (45)	HIIT: *n* = 17 MICT: *n* = 16	*Per session:* HIIT: ~1,042 kJ per session‡ MICT: ~1,025 kJ per session‡ *Total intervention:* HIIT: ~62,520 kJ‡ MICT: ~61,500 kJ‡	DEXA (total body fat %)	HIIT: 40.6 (4.0) MICT: 41.1 (4.2)	HIIT: 36.6 (4.3)** MICT: 39.0 (4.0)*	NR
Koubaa *et al.* (46)	HIIT: *n* = 14 MICT: *n* = 15	'Same training load' *Per session:* HIIT and MICT: ~1,781 kJ per session‡ *Total intervention:* HIIT and MICT: ~64,116 kJ‡	Sum of 4 skinfolds: supra-iliac, biceps, triceps, subscapular (total body fat, %)	HIIT: 33.8 (6.7) MICT: 33.7 (6.7)	HIIT: 31.8 (7.1)* MICT: 28.8 (5.1)*	HIIT: −2.0 (0.5)* MICT: −4.9 (2.4)*
Shepherd *et al.* (47)	SIT: *n* = 8 MICT: *n* = 8	NR	DEXA (fat mass, kg)	SIT: 14.2 (4.5) MICT: 12.3 (4.2)	SIT: 13.6 (4.2) MICT: 12.2 (4.7)	NR
Keating *et al.* (48)	SIT: *n* = 13 MICT: *n* = 13	*Per session:* SIT: ~397 kJ per session‡ MICT: ~1,183 kJ per session‡ *Total intervention:* SIT: ~14,292 kJ‡ MICT: ~42,588 kJ‡	DEXA Total (%)	SIT: 41.5 (6.1) MICT: 43.2 (7.2)	SIT: 41.0 (7.2) MICT: 42.2 (8.3)**	SIT: −0.3 (0.6) MICT: −2.6 (1.1)**
			Trunk (%)	SIT: 43.8 (5.4) MICT: 45.4 (6.1)	SIT: 43.5 (5.8) MICT: 44.2 (6.9)	SIT: 0.7 (0.4) MICT: −3.1 (1.6)
			Android (%)	SIT: 48.7 (4.7) MICT: 49.8 (5.4)	SIT: 48.7 (4.7) MICT: 48.6 (6.1)**	SIT: 0.8 (0.6) MICT: −2.7 (1.3)**
			Total body fat (kg)	SIT: 30.4 (7.5) MICT: 33.1 (6.0)	SIT: 30.2 (8.7) MICT: 32.1 (4.0)	NR
Lunt *et al.* (49)	HIIT: *n* = 16 MICT: *n* = 17	NR	DEXA (total body fat, %)	HIIT: 39.5 (5.4) MICT: 39.5 (5.2)	HIIT: 39.0 (5.6) MICT: 39.0 (5.3)	NR
Nalcakan *et al.* (35)	SIT: *n* = 8 MICT: *n* = 7	NR	Sum of 8 skinfolds (total body fat, %)	SIT: 16.5 (3.7) MICT: 15.8 (2.6)	SIT: 15.3 (3.2)* MICT: 14.9 (2.6)*	SIT: −7.3* MICT: −5.7*

(*Continues*)

Table 3 (Continued)

Reference	Mode	Energy expenditure	Body composition assessment method	Pre, mean (SD)	Post, mean (SD)	Change score
Mohr *et al.* (34)	SIT: *n* = 21 MICT: *n* = 21	NR	DEXA Total body fat (%)	SIT: 43.1 (5.0) MICT: 44.1 (5.5)	SIT: 41.4 (5.5)* MICT: 42.1 (4.6)*	NR
			Total fat mass (kg)	SIT: 34 (8.2)† MICT: 38 (13.7)†	SIT: 33 (6.9)†* MICT: 36 (13.7)†*	SIT: −1.1 (0.9)* MICT: −2.2 (1.4)*
Saski *et al.* (60)	HIIT: *n* = 12 MICT: *n* = 12	*Per session:* HIIT and MICT: ~593 kJ per session‡ *Total intervention:* HIIT and MICT: ~21,348 kJ‡	Bioelectrical impedance analysis (total body fat, %)	HIIT: 21.4 (4.2) MICT: 19.5 (4.8)	HIIT: 20.9 (4.5) MICT: 19.9 (4.8)	NR
			MRI SAT (cm^2)	HIIT: 153 (55.4) MICT: 132 (45.0)	HIIT: 160 (66.8) MICT: 132 (41.6)	NR
			VAT (cm^2)	HIIT: 59 (31.2) MICT: 50 (20.8)	HIIT: 57 (13.8) MICT: 52 (27.7)	
Cocks *et al.* (62)	SIT: *n* = 8 MICT: *n* = 8	NR	DEXA (total body fat, %)	SIT: 32.2 (5.9) MICT: 30.9 (5.1)	SIT: 31.8 (6.5) MICT: 29.6 (4.8)**	NR
Cheema *et al.* (50)	HIIT: *n* = 6 MICT: *n* = 6	180 MET min per session	Skinfolds, 6 sites (total body fat, %)	HIIT: 33.5 (10.1) MICT: 37.3 (13.1)	HIIT: 29.5 (11.1)* MICT: 35.0 (11.3)	HIIT: −13.2 (10.6)* MICT: −5.4 (7.5)
Devin *et al.* (63)	HIIT: *n* = 21 MICT: *n* = 14	*Per session:* HIIT: ~1,025 kJ‡ MICT: ~982 kJ‡	DEXA Fat mass (kg)	HIIT: 25.1 (8.5) MICT: 27.3 (9.3)	HIIT: 24.3 (8.6)* MICT: 27.1 (9.4)	HIIT: −0.74 (0.65)* MICT: −0.21 (0.99)
		Total intervention: HIIT: ~12,305 kJ‡ MICT: ~11,784 kJ‡	Total body fat (%)	HIIT: 34.3 (7.4) MICT: 38.9 (7.8)	HIIT: 33.3 (7.9)* MICT: 38.5 (8.3)	HIIT: −1.0 (1.0)* MICT: −0.38 (1.34)
Elmer *et al.* (61)	HIIT: *n* = 6 MICT: *n* = 6	HIIT and MICT: Weeks 1–2: ~1,075 ± 181 kcal week^{-1} Weeks 3–4: ~1,139 ± 191 kcal week^{-1} Weeks 5–6: ~1,215 ± 185 kcal week^{-1}	DEXA Total body fat (%)	HIIT: 28.2 (7.0) MICT: 27.9 (8.0)	HIIT: 27.3 (7.7) MICT: 26.4 (9.0)	NR
		Weeks 7–8: ~1,282 ± 195 kcal week^{-1} *Per session average:* 1,075–1,282 kcal week^{-1}	Android fat (%)	HIIT: 35.0 (8.2) MICT: 36.8 (9.6)	HIIT: 33.1 (9.9) MICT: 34.2 (11.4)*	NR
		Total intervention: ~39,614 kJ‡	Gynoid fat (%)	HIIT: 34.0 (6.5) MICT: 32.2 (7.6)	HIIT: 34.0 (7.4) MICT: 31.1 (8.4)	
Fisher *et al.* (51)	SIT: *n* = 13 MICT: *n* = 10	NR	DEXA (total body fat, %)	SIT: 34.1 (6.5) MICT: 29.5 (5.1)**	NR	SIT: −0.9 (1.4) MICT: −1.3 (2.2)**
Martins *et al.* (36)	SIT: *n* = 6 MICT: *n* = 6	*Per session:* SIT and MICT: 1,050 kJ	DEXA Trunk fat (%)	NR	NR	SIT: −0.6 (1.8)* MICT: −0.01 (2.9)*
		Total intervention: SIT and MICT: 37,800 kJ	Leg fat (%)	NR	NR	SIT: −1.0 (1.7)* MICT: −0.01 (2.6)*

(*Continues*)

Table 3 (Continued)

Reference	Mode	Energy expenditure	Body composition assessment method	Pre, mean (SD)	Post, mean (SD)	Change score
Shepherd *et al.* (52)	HIIT: *n* = 46	NR	BIA			
	MICT: *n* = 44		Fat mass (kg)	HIIT: 26.0 (10.2)	HIIT: 25.2 (9.9)	HIIT: −0.8 (−1.5 to −0.1)*
				MICT: 24.7 (8.5)	MICT: 23.7 (9.5)	MICT: −1.0 (−1.7 to −0.3)*
			Fat mass (%)	HIIT: 31.6 (7.9)	HIIT: 30.8 (7.5)	HIIT: −0.8 (−1.5 to −0.1)*
				MICT: 32.0 (7.6)	MICT: 30.9 (8.7)	MICT: −1.0 (−1.7 to −0.3)*
			Trunk fat (kg)	HIIT: 13.2 (5.1)	HIIT: 12.8 (4.9)	HIIT: −0.4 (−0.9 to 0.0)*
				MICT: 13.2 (4.4)	MICT: 12.6 (4.9)	MICT: −0.6 (−1.1 to −0.1)*
Sim *et al.* (53)	SIT: *n* = 10	SIT$^{¥}$: 226 (44) kJ	DEXA (total body fat, %)	SIT: 32.0 (2.9)	SIT: 30.9 (2.7)	NR
	MICT: *n* = 10	MICT$^{¥}$: 228 (44) kJ		MICT: 31.1 (5.0)	MICT: 30.2 (6.5)	
Zhang *et al.* (54)	HIIT: *n* = 12	Oxygen cost of a single session:	Computed tomography (cross sectional slice at L4–L5 inter-vertebral space)			
	MICT: *n* = 12	HIIT: 49.8 (4.7) L				
		MICT: 50.7 (4.7)L				
		Per session:				
		HIIT: ~1,046 kJ‡	Abdominal visceral fat (cm^2)	HIIT: 64.9 (17.5)	HIIT: 53.1 (14.5)**	HIIT: −11.8 (−17.5, −6.0)**
		MICT: ~1,065 kJ‡		MICT: 60.4 (15.5)	MICT: 55.6 (14.9)	MICT: −4.8 (−10.5, 0.7)
		Total intervention:	Abdominal subcutaneous fat (cm^2)	HIIT: 255.3 (77.4)	HIIT: 205.6 (68.3)**	HIIT: −49.7 (−65.7, −33.7)**
		HIIT: ~50,208 kJ‡		MICT: 229.4 (57.4)	MICT: 204.0 (55.7)*	MICT: −25.4 (−43.5, −7.3)*
		MICT: ~51,120 kJ‡	Bioelectrical impedance analysis			
			Total body fat (%)	HIIT: 31.3 (3.6)	HIIT: 28.2 (3.9)*	HIIT: −3.1 (−3.8, −2.4)*
				MICT: 32.0 (2.4)	MICT: 29.2 (2.4)*	MICT: −2.8 (−3.6, −2.0)*
			Fat mass (kg)	HIIT: 19.4 (5.0)	HIIT: 17.5 (4.8)*	HIIT: −1.9 (−2.4, −1.5)*
				MICT: 19.3 (2.8)	MICT: 17.7 (2.8)*	MICT: −1.7 (−2.2, −1.2)*
Higgins *et al.* (55)	SIT: *n* = 23	*Per session:*	DEXA			
	MICT: *n* = 29	SIT: 541.8 (104.6) kJ	Fat mass (kg)	SIT: 33.7 (7.9)	SIT: 32.5 (7.1)	SIT: −1.2 (1.9)**
		MICT: 553.5 (138.1) kJ		MICT: 36.1 (8.6)	MICT: 35.9 (8.5)	MICT: 0.2 (1.4)
		Total intervention:				
		SIT: ~9,752 kJ	Fat mass (%)	SIT: 42.2 (4.8)	SIT: 41.2 (4.8)	SIT: −1.0 (1.4)**
		MICT: ~9,963 kJ		MICT: 44.5 (4.8)	MICT: 44.2 (4.4)	MICT: −0.3 (1.1)
			Android fat mass (kg)	SIT: 2.9 (0.9)	SIT: 2.7 (0.8)	SIT: −0.2 (0.3)**
				MICT: 3.1 (1.0)	MICT: 3.1 (1.0)	MICT: −0.0 (0.2)
Hwang *et al.* (56)	HIIT: *n* = 15	*Per session:*	DEXA			
	MICT: *n* = 14	HIIT: 940 (59) kJ	Body fat (%)	HIIT: 38.8 (7.0)	HIIT: 37.9 (7.0)	NR
		MICT: 982 (59) kJ		MICT: 37.5 (8.2)	MICT: 37.2 (7.4)	
		Total intervention:				
		HIIT: ~30,080 kJ	Fat mass (kg)	HIIT: 28.5 (7.4)	HIIT: 27.8 (7.7)	NR
		MICT: ~31,424 kJ		MICT: 29.0 (7.9)	MICT: 28.4 (7.1)	
Panissa *et al.* (57)	HIIT: *n* = 11	'Load matched'	Skinfold thickness			
	MICT: *n* = 12		Fat mass (kg)	HIIT: 21.4 (7.8)	HIIT: 19.4 (7.7)	HIIT: −9.6 (NR)*
				MICT: 17.2 (3.9)	MICT: 16.4 (3.7)	MICT: −2.0 (NR)*

(*Continues*)

Table 3 (Continued)

Reference	Mode	Energy expenditure	Body composition assessment method	Pre, mean (SD)	Post, mean (SD)	Change score
			Relative fat mass (kg)	HIIT: 30.4 (6.2) MICT: 27.7 (3.6)	HIIT: 27.5 (6.2) MICT: 26.4 (3.6)	HIIT: −9.6 (NR)* MICT: −2.0 (NR)*
			Sum of 7 skinfolds (mm)	HIIT: 173.7 (55.7) MICT: 149.0 (52.3)	HIIT: 149.0 (52.3) MICT: 140.9 (27.5)	HIIT: −9.6 (NR)* MICT: −4.6 (NR)*
Gillen *et al.* (58)	SIT: n = 9 MICT: n = 9	*Per session:* SIT: ~60 kJ MICT: ~310 kJ *Total intervention:* SIT: ~1,860 kJ MICT: ~9,920 kJ	Whole-body densitometry via air displacement (BodPod®) (percent fat, %)	SIT: 30.0 (7.0) MICT: 27.0 (10.0)	SIT: 28.0 (8.0)* MICT: 25.0 (10.0)*	NR
Ramos *et al.* (59)	HIIT: n = 22 MICT: n = 21	*Per session:* HIIT: ~1,365 (490) kJ MICT: ~740 (294) kJ *Total intervention:* HIIT: ~65,534 (23,493) kJ MICT: ~59,199 (17,209) kJ	DEXA Total body fat (%)	HIIT: 42.3 (6.4) MICT: 38.9 (8.8)	HIIT: 41.8 (7.0) MICT: 38.5 (9.1)	NR
			Trunk fat (%)	HIIT: 44.9 (5.5) MICT: 42.3 (8.5)	HIIT: 44.6 (6.1) MICT: 41.8 (8.6)	NR

Patient or population: All human participants included in trials comparing HIIT or SIT with MICT.
Intervention: HIIT –protocols targeting intensities between 80% and 100% peak heart rate or aerobic capacity interspersed with recovery periods – SIT – 'all-out' sprints (>100% of the maximal rate, VO_{2max}) interspersed with recovery periods.
Comparison: MICT – continuous steady-state aerobic exercise that elicits a heart rate response of 55–69% HR_{max} or elevates the rate of oxygen consumption to 40–59% of VO_{2max}.
Outcome: body adiposity (total or regional body fat percentage or fat mass).
*Significant group by time interaction.
**Significant between-group effect.
†Extrapolated from graph.
¥Based on in-text citation to previous methodology paper.
‡Calculated by authors using reported data for group mean VO_{2max}, protocol intensity/duration and the assumption that the metabolic cost of exercising at a VO_2 of 1 L min^{-1} expends 21 kJ min^{-1}. Values reported as mean (SD); in instances where results presented as mean (SEM), SEM was converted to SD using SD = SEM × Sqrt^*n*.
DEXA, dual-energy X-ray absorptiometry; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; MRI, magnetic resonance imaging; NR, not reported; SAT, subcutaneous adipose tissue; SD, standard deviation; SEM, standard error of the mean; SIT, sprint interval training; VAT, visceral adipose tissue.

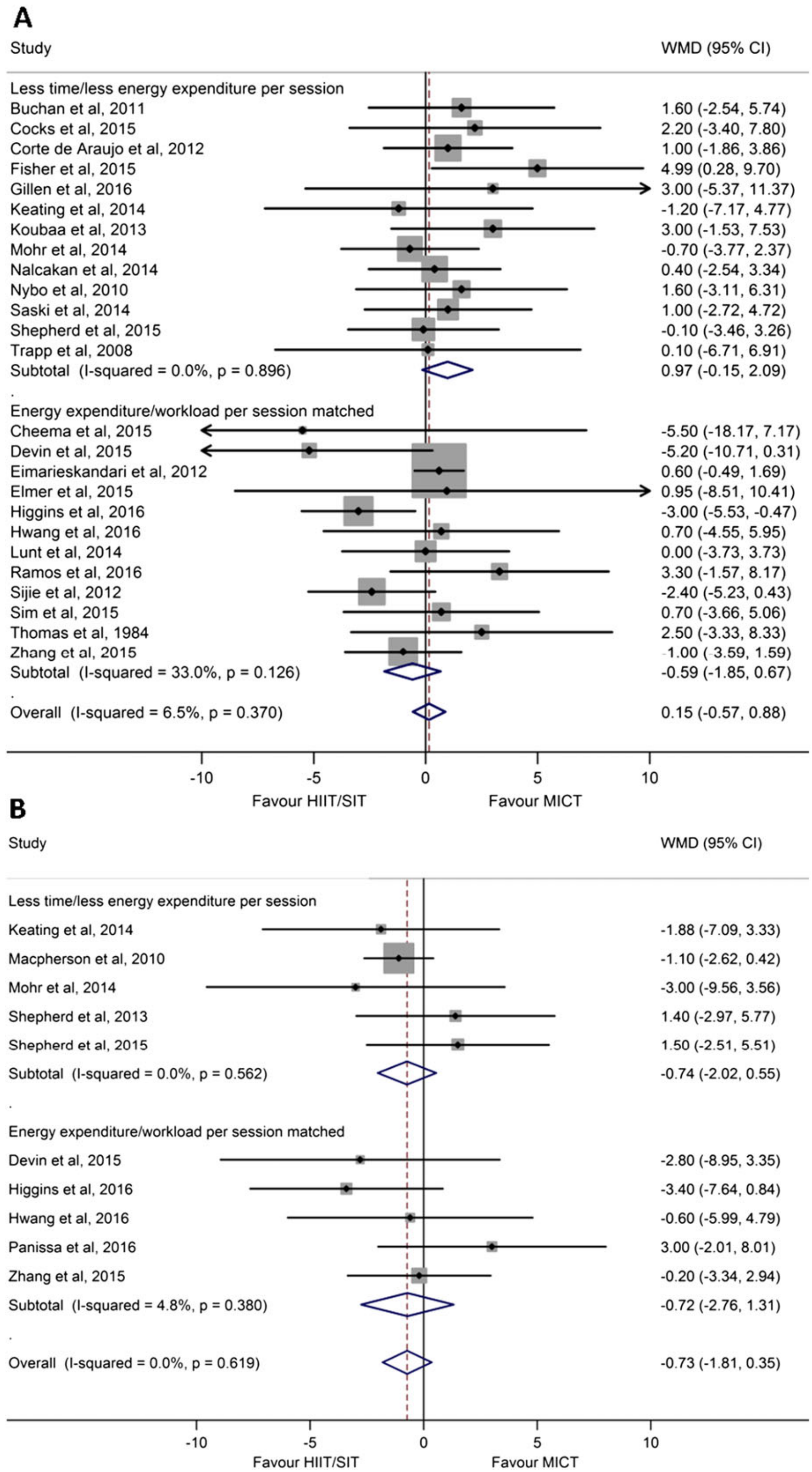

Figure 2 Meta-analysis for the comparison of HIIT/SIT versus MICT for (A) total body fat percentage (%) and (B) fat mass (kg) with subgroup analyses for studies employing HIIT/SIT protocols lower in time commitment and energy expenditure than MICT, and for studies in which the HIIT/SIT and MICT protocols were described as 'matched' for energy expenditure/workload. HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; SIT, sprint interval training; WMD, weighted mean difference. [Colour figure can be viewed at wileyonlinelibrary.com]

meta-analysis and meta-regression of the pooled effect for the comparison of HIIT/SIT versus MICT on total body fat (%) and total fat mass (kg), by characteristics of studies, are presented in Fig 2A,B, respectively. Outcomes of the meta-regression are presented in Table 4. No effect of mode of comparison (HIIT or SIT), sex, intervention duration, BMI, age or study quality, and sex was observed.

Sensitivity analyses

A series of sensitivity analyses did not substantially change these results. The funnel plots and Begg's tests showed no evidence of publication bias for the studies from either HIIT/SIT (p = 0.11) or MICT (p = 0.48). Influence analyses did not show important changes to the pooled ESs as a result of any individual study (Fig S3A and S3B for total body fat and total fat mass, respectively). Finally, in order for a new study to change the conclusions of our meta-analysis, based on the statistical significance of the pooled effects and overall heterogeneity, a new study would need to present either a large ES or a smaller standard error than that found in the studies that were part of the present meta-analyses (Fig. 3).

Discussion

This systematic review with meta-analysis assessed the efficacy of HIIT/SIT compared with that of MICT for the modulation of body adiposity. The analysis combined 31 studies (28 for meta-analysis) involving a total of 873 participants. Low sample size is inherent in supervised exercise-based intervention trials, and only four studies in this review recruited more than 20 volunteers in each group (34,52,55,59), and therefore, studies potentially lack the power to detect between-group differences. By pooling the data, we found no evidence to support the superiority of either HIIT/SIT or MICT for body fat reduction. Indeed, when interval training protocols were matched for energy expenditure/workload, similar benefits were observed. While the physiological nature of HIIT and SIT is different, there were no differences between the effect of HIIT or SIT on body composition outcomes. Both HIIT/SIT and MICT were equally beneficial for eliciting small reductions in total body fat (ES: −1.26% in HIIT/SIT and −1.45% MICT) and in fat mass (ES: −1.38 kg in HIIT/SIT and −0.91 kg in MICT). However, when comparing studies that employed HIIT/SIT interventions that incorporated less time and/or less energy expenditure than MICT, there was tendency to

Table 4 General meta-analyses and meta-regression of the pooled effect of comparison HIIT/SIT versus MICT on total body fat (%) and fat mass (kg) by characteristics of studies

	Total body fat			Fat mass		
	n	Effect (95% CI)	*p*	*n*	Effect (95% CI)	*p*
Comparison			0.870			0.220
HIIT	15	0.29 (−0.47; 1.06)		5	0.37 (−1.58; 2.32)	
SIT	10	0.19 (−1.34; 1.71)		5	−1.22 (−2.51; 0.08)	
Sex			0.618			0.689
Combined	8	0.67 (−0.82; 2.15)		4	−0.83 (−2.17; 0.50)	
Female	6	0.58 (−1.15; 2.31)		3	0.19 (−2.45; 2.83)	
Male	11	−0.05 (−1.01; 0.91)		3	−1.44 (−4.61; 1.73)	
Duration (weeks)			0.976			0.828
<12	11	0.18 (−1.12; 1.49)		7	−0.59 (−1.93; 0.74)	
12+	14	0.05 (−1.03; 1.13)		3	−0.99 (−3.48; 1.50)	
Body mass index			0.833			0.226
Not reported	5	1.08 (−0.81; 2.97)		2	−1.20 (−2.68; 0.29)	
Normal	2	0.79 (−2.47; 4.06)		2	2.09 (−1.20; 5.38)	
Overweight	11	−0.33 (−1.66; 1.00)		5	−0.35 (−2.31; 1.61)	
Obese	7	0.12 (−1.39; 1.64)		1	−3.40 (−7.64; 0.84)	
Age (years)			0.728			0.974
<30	14	0.26 (−0.83; 1.35)		5	−0.57 (−2.10; 0.96)	
30+	10	−0.10 (−1.50; 1.30)		5	−0.77 (−3.10; 1.57)	
Quality score			0.213			0.739
Low	10	0.46 (−0.38; 1.30)		4	−0.31 (−2.24; 1.62)	
Middle	9	0.60 (−1.05; 2.25)		2	0.01 (−4.01; 4.02)	
High	6	−0.84 (−2.50; 0.81)		4	−1.31 (−3.41; 0.78)	
Overall*	25	0.16 (−0.57; 0.81)		10	−0.73 (−1.81; 0.35)	

*Random effect size.

HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; SIT, sprint interval training.

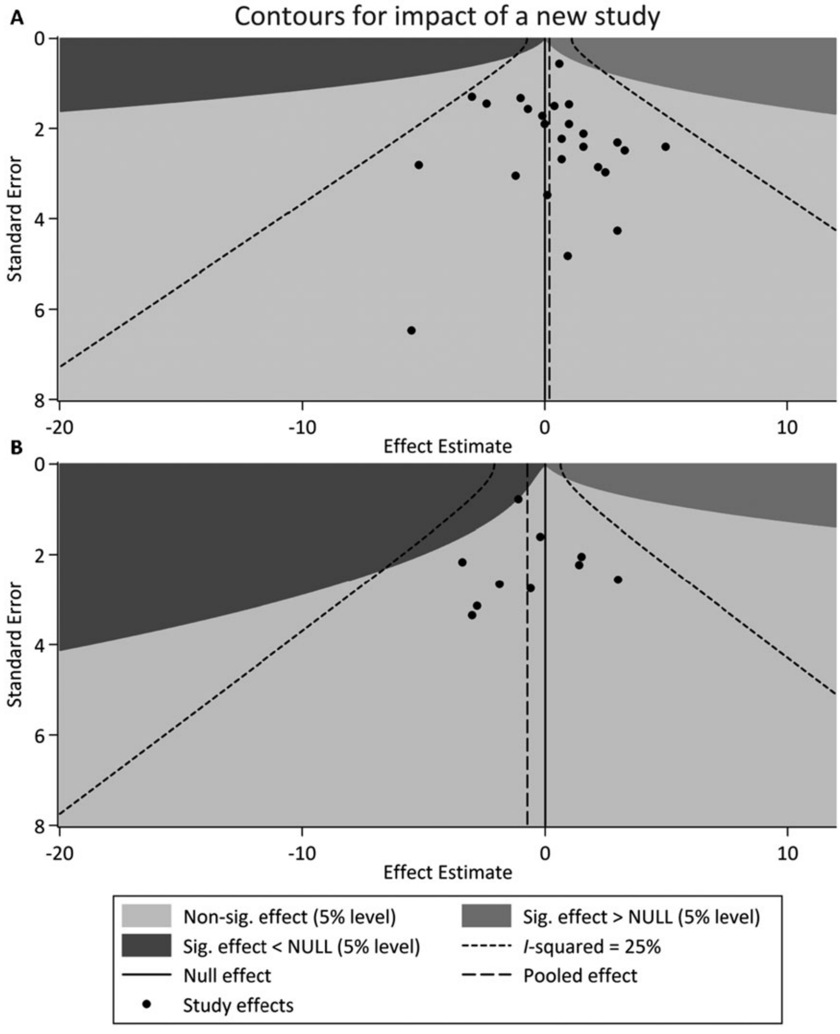

Figure 3 Contour plots for the impact of a new study for (A) total body fat percentage (%) and (B) fat mass (kg).

favour MICT for total body fat reduction. The majority of studies inferred total body adiposity via dual-energy X-ray absorptiometry (*n* = 18), bioelectrical impedance analysis (*n* = 5) and skinfolds (*n* = 5), and few (*n* = 2) quantified VAT with accurate imaging techniques. Only six studies (19%) reported blinding assessors to treatment allocation, and 15 studies (48%) reported on the frequency and severity of adverse events. To ensure the robustness of our results, we performed a sensitivity analysis and removed each study one by one, with no studies influencing the outcome of our analyses. Our analyses of contour plots demonstrate that new studies will require either a very large ES or a much smaller standard error than that found in the present studies, to influence the outcome of these analyses.

As HIIT/SIT is regularly touted as a time-efficient method for achieving the same, or superior, health benefits to traditional MICT, our findings have important implications for how exercise is promoted in both the scientific and lay media. Firstly, the results suggest that for body fat reduction, HIIT/SIT is an effective alternative to MICT and achieves equivalent levels of fat loss when similar time commitment and/or energy expenditure is used. HIIT/SIT can therefore be advocated particularly when cardiorespiratory fitness, blood pressure, insulin sensitivity or muscle mass improvement is a primary target (15,16,18). Secondly, whether HIIT/SIT is an effective 'time-efficient' exercise strategy for body fat management remains contentious. To the contrary, we observed a near-significant superiority of MICT over HIIT/SIT when HIIT/SIT training time and/or energy expenditure was less. Nevertheless, we note that all-out SIT may provide similar benefits in less time and that studies in this review observed comparable fat reductions in SIT protocols with ~13–58% less time (33–36,58) than MICT and thus warrants further investigation. However, SIT protocols are extremely difficult and unlikely to be tolerated or enjoyed by previously inactive individuals or populations with obesity (49,64). Lastly, neither HIIT/SIT nor MICT on their own resulted in clinically meaningful reductions (>5%

reduction (65)) in total body fat. Regular exercise is an integral component of long-term weight management (1) and is considered a 'polypill' for its benefits beyond weight loss (66). However, unless implemented in very large volumes (6), short-term exercise in isolation (including HIIT/SIT) is unlikely to produce clinically meaningful fat loss.

Notwithstanding its apparently small effect, the benefit of HIIT/SIT on fat loss has been proposed to reflect the following: alterations in metabolism (e.g. due to hormonal factors), an augmented excess post-exercise oxygen consumption (EPOC) and changes in appetite responses (19). Given the variation in exercise intensity and duration between MICT and HIIT/SIT, the metabolic responses to bouts of MICT and HIIT/SIT will differ. In general, a bout of MICT would have a lower rate of energy expenditure but greater proportion of fat as a substrate with a sustained high release of free fatty acids (FFAs) and subsequent oxidation of FFA. In contrast, a bout of HIIT/SIT is associated with high hormonally driven rates of adipose lipolysis, but not necessarily with a high rate of FFA oxidation, owing to the relative brevity of the bout. While predominantly anaerobic in nature, acute bouts of SIT significantly increase catecholamines (epinephrine and norepinephrine) and growth hormone, which stimulate lipolysis (67,68) but not necessarily fatty acid oxidation (69,70) or ultimately fat loss. Additionally, when matched for mechanical work outputs, HIIT protocols have demonstrated a significantly greater contribution of carbohydrate at the expense of fat compared with MICT (71). Therefore, as HIIT/SIT does not appear to augment lipolysis or fatty acid oxidation, but has greater potential for muscle glycogen depletion than MICT, it is plausible that the benefit of HIIT/SIT on fat reduction may occur in the post-exercise period.

After cessation of exercise, the metabolic rate remains slightly elevated for a period of time (usually 1–2 and up to 14 h with high intensities), known as EPOC. During this phase, the rate of lipolysis and fat oxidation is elevated in an exercise intensity-dependent response (72), mediated by beta-adrenergic stimulation (73), which partly facilitates the replenishment of relatively limited muscle and hepatic glycogen stores (74). When compared with bed rest, HIIT protocols (10 × 4-min intervals at 85% HR_{peak} with 2-min recovery, and 10 × 1-min intervals at 90% HR_{peak} with 1-min recovery) have been shown to increase total energy expenditure, exercise energy expenditure and EPOC. However, these benefits may be short lived and diminish as little as 1 h following exercise (75). Overall, it appears that EPOC is unlikely to account for any apparent greater fat loss potential with HIIT/SIT (70,71,76).

While it appears that exercise session energy expenditure is integral in any benefit of exercise on body adiposity reduction, other factors such as habitual diet and physical activity behaviours may also contribute to the differences observed among intervention via their effects on energy expenditure. Our review of study quality showed that these factors were generally poorly controlled in the included studies with only eight studies (26%) monitoring and reporting data for both variables (36,38,40,48,54,55,59,60). It is therefore possible that changes in these may have impacted upon the outcomes of the interventions. For instance, Koubaa and co-workers (46) observed a 6-cm reduction in waist circumference after 12 weeks of MICT in obese children, which is more than would be expected with an intervention employing exercise in isolation. To date, there has been no long-term investigation on the impact of HIIT/SIT on changes in sedentary behaviour or habitual physical activity levels; however, one short-term investigation demonstrated that a 10-d supervised HIIT intervention led to an increase in moderate-intensity physical activity levels in addition to maintenance of the HIIT protocol in the 1 month following intervention (77).

Compensatory mechanisms have been shown to result in greater or smaller than expected body fat reductions in response to different exercise doses (78). Research examining the effect of HIIT/SIT on appetite and post-exercise energy intake has produced inconsistent results. Comparable effects of HIIT/SIT and MICT on appetite perceptions (including hunger, fullness, satiation and desire to eat) have been demonstrated in men (79,80) and in children (81) with no differences in *ad libitum* energy intake between HIIT and MICT (80–82), but significantly less with SIT than MICT (79). Compared with low intensity exercise, high-intensity exercise has been shown to reduce energy intake relative to the energy cost of exercise to a greater extent, potentiating a greater negative energy balance (83). More recently, HIIT has shown to elicit more beneficial changes in appetite regulation than MICT (53), and SIT has been found to suppress post-exercise energy intake to a greater extent in men who are overweight (79) and to reduce perceptions of post-exercise hunger and fullness in healthy men (70) significantly more than MICT. However, an acute bout of MICT was shown to reduce post-exercise appetite perceptions to a greater extent than SIT (84) and led to a greater 24-h energy deficit in MICT than SIT in healthy men when the exercise session energy expenditure was combined with the post-exercise energy expenditure (84).

It is recommended that future studies should objectively assess the impact of interventions on habitual physical activity levels and diet, and energy expenditure and examine the adoption and long-term adherence to HIIT and MICT protocols in real-world settings. Studies should also report training information regarding the compliance to the set training intensities. Given the interest in the safety of HIIT and SIT in clinical populations, studies should adequately report the frequency and severity of adverse events and detail how they were monitored and reported. In order to clearly discern the comparable efficacy of HIIT/SIT versus

MICT on body fat reduction, future studies should be sufficiently powered to detect between-group changes in body fat outcomes. While it is difficult to blind participants to group allocation in exercise training studies, assessors of outcomes should be blinded to treatment allocation. Furthermore, high-resolution quantitative imaging techniques, e.g. magnetic resonance imaging/computed tomography, should be used for future research aimed at evaluating the benefit of HIIT/SIT in comparison with MICT on visceral adiposity, which is known to be associated with cardiovascular and metabolic disease risk.

It is noteworthy that the magnitude of changes in total body fat with either modality was small in terms of clinical meaningfulness. Furthermore, given the health benefits of exercise beyond fat loss, the performance of regular HIIT in populations with obesity can be beneficial. Moreover, HIIT may be used in conjunction with MICT and/or dietary intervention (an integral component of obesity management) to achieve fat and weight reduction (85).

Conclusion

High-intensity interval training/sprint interval training appears to provide similar benefits to MICT for body fat reduction; however, HIIT/SIT is not a superior method for fat loss when directly compared with MICT. HIIT/SIT protocols that are lower in time commitment and expend less energy may not confer the same benefit on total body fat reduction compared with MICT. While both HIIT/SIT and MICT significantly reduced total body fat and fat mass, neither produced clinically meaningful reductions in body fat. Therefore, while interval training is an effective method for improving cardiorespiratory fitness, if body fat reduction is a therapeutic target, exercise interventions require an adequate volume of energy expenditure, which may not be possible with HIIT or SIT.

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Conflict of interest statement

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Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article. http://dx.doi.org/10.1111/obr.12536

Figure S1. Within-group HIIT/SIT pre-post effect on (a) total body fat percentage (%) and (b) fat mass (kg).
Figure S2. Within-group MICT pre-post effect on (a) total body fat percentage (%) and (b) fat mass (kg).
Figure S3. Influence Plots.
Table S1. Study Quality.
Table S2. Search Term Combination used in PubMed.

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