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REVIEW ARTICLE

Effect of High-Intensity Interval Training on Total, Abdominal and Visceral Fat Mass: A Meta-Analysis

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Abstract
Background High-intensity interval training (HIIT) is promoted as a time-efficient strategy to improve body composition.
Objective The aim of this meta-analysis was to assess the efficacy of HIIT in reducing total, abdominal, and visceral fat mass in normal-weight and overweight/obese adults.
Methods Electronic databases were searched to identify all related articles on HIIT and fat mass. Stratified analysis was performed using the nature of HIIT (cycling versus running, target intensity), sex and/or body weight, and the methods of measuring body composition. Heterogeneity was also determined
Results A total of 39 studies involving 617 subjects were included (mean age 38.8 years ± 14.4, 52% females). HIIT significantly reduced total ($p = 0.003$), abdominal ($p = 0.007$), and visceral ($p = 0.018$) fat mass, with no differences between the sexes. A comparison showed that running was more effective than cycling in reducing total and visceral fat mass. High-intensity (above 90% peak heart rate) training was more successful in reducing whole body adiposity, while lower intensities had a greater effect on changes in abdominal and visceral fat mass. Our analysis also indicated that only computed tomography scan or magnetic resonance imaging showed significant abdominal and/or visceral fat-mass loss after HIIT interventions.
Conclusion HIIT is a time-efficient strategy to decrease fat-mass deposits, including those of abdominal and visceral fat mass. There was some evidence of the greater effectiveness of HIIT running versus cycling, but owing to the wide variety of protocols used and the lack of full details about cycling training, further comparisons need to be made. Large, multicenter, prospective studies are required to establish the best HIIT protocols for reducing fat mass according to subject characteristics.

Key Points

High-intensity interval training protocols are effective in decreasing fat-mass deposits, including abdominal and visceral fat mass.

Comparison of running and cycling shows that running is potentially more successful in reducing total and visceral adipose tissues.

1 Introduction

Currently, 2.1 billion individuals, approximately 30% of the world's population, are overweight or obese [1]. The escalating obesity epidemic in the last decade has been accompanied by an increase in metabolic disorders such

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as insulin resistance, type 2 diabetes, and cardiovascular diseases. The World Health Organization defines overweight and obesity as an abnormal accumulation or excess of fat mass that can adversely affect health [2]. In addition, fat localization is a major determinant of the occurrence of metabolic disorders [3], with abdominal adipose tissue being particularly involved. It is also important to differentiate white adipose tissue in subcutaneous adipose tissue, which is characterized by high storage capacity, from visceral adipose tissue, which is metabolically more active. In visceral adipose tissue, greater lipolysis leads to higher free fatty acid secretion, which in turn results in ectopic deposits and/or direct transport to the liver by the portal vein. Visceral adipose tissue also releases several proinflammatory factors, including proinflammatory cytokines (tumor necrosis factor [TNF]-α, interleukin [IL]-6, IL-1β), hormones (leptin, resistin), and other molecules such as monocyte chemoattractant protein-1 (MCP-1), that participate in the establishment of chronic inflammation related to insulin resistance [4]. Visceral adipose tissue is therefore highly correlated with cardiovascular risks [5].

Against this background, effective fat-loss strategies, including dietary or physical activity interventions, or both, are required. In the short- and long-term, programs based on nutritional recommendations alone are less effective than those also including physical activity [6]. Current guidelines recommend moderate-intensity continuous training (MICT) [7], mainly because it can be maintained over a long period, thereby promoting fat mobilization and oxidation [8, 9]. MICT has positive cardiovascular and metabolic effects but it often leads to little or no fat loss [10, 11]. Conversely, emerging evidence on high-intensity interval training (HIIT) suggests that this exercise modality could lead to greater adipose tissue loss than low/moderate continuous training [12–14], and could more effectively reduce abdominal and visceral fat mass, which are the most dangerous fat deposits [15, 16]. Recent systematic reviews and meta-analyses have compared the effects of MICT versus HIIT on fat-mass loss; however, owing to the small number of comparative studies, abdominal and visceral fat mass have not been examined [13, 14]. Thus, the aim of the present meta-analysis was to assess the effectiveness of HIIT in reducing total, abdominal, and visceral fat mass in normal-weight and overweight/obese adults. We also analyzed the issues regarding the nature of HIIT (cycling versus running, target intensity), sex, body weight, and the methods used to measure body composition.

2 Methods

2.1 Literature Search Strategy

A systematic literature search of the PubMed and Google Scholar electronic databases, from January 1980 until July 2017, was conducted using the keywords ‘high-intensity interval training’, ‘high-intensity intermittent exercise’, and ‘aerobic interval training’. The reference list of the publications selected was also manually screened to detect references not found during the initial electronic search. Publications in English and French were retained for analysis.

2.2 Inclusion and Exclusion Criteria

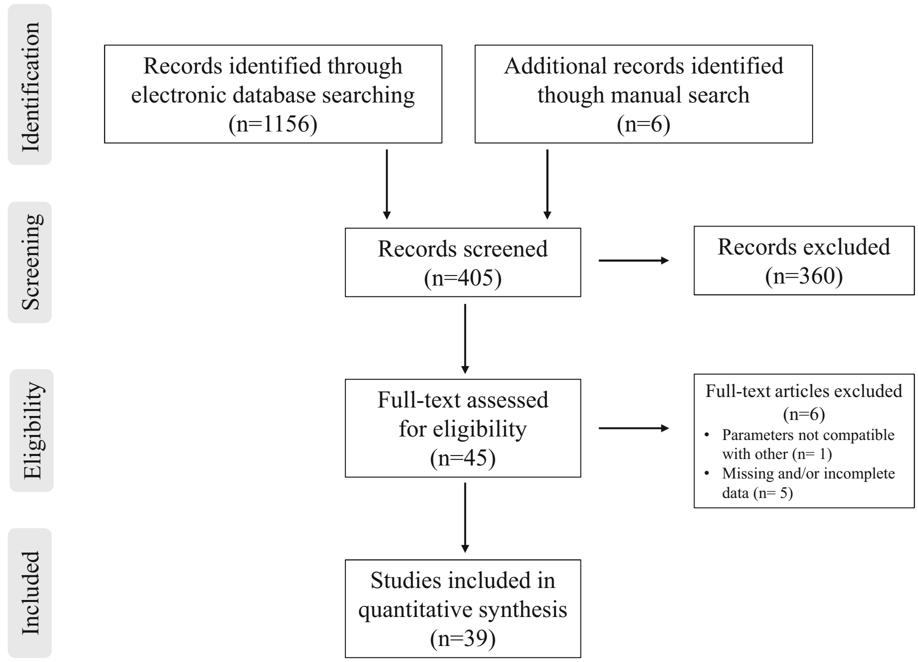
2.2.1 Type of Interval Training

In the HIIT modality, short bursts of high-intensity exercise are alternated with periods of lower-intensity effort or complete rest for recovery [17]. In the last few years, HIIT has grown in popularity among athletes or as a strategy to counteract the adverse effects of metabolic disorders [18]. This has led to a wide range of terms to describe HIIT protocols, such as aerobic interval training (AIT) or high-intensity intermittent exercise (HIIE). Recently, Weston et al. suggested a simple classification of the different modalities based on exercise intensity [17]. Accordingly, the term HIIT should be used to design protocols with a target intensity ‘near the maximal’ effort (i.e. between 80 and 100% of the peak heart rate [PHR]), while sprint interval training (SIT) is more appropriate for ‘all out’ or ‘supramaximal’ efforts ($\geq$ 100% maximal oxygen consumption, $\dot{V}O_2$max). In addition, physiological and metabolic adaptations are different in SIT and HIIT [19, 20]. For these reasons, we excluded from our analysis studies that involved SIT. When publications referred incorrectly to ‘SIT’ or ‘Wingate’ protocols (i.e. when subjects performed with an intensity level below 100% of the PHR), the data were nevertheless included. In our meta-analysis, only running, cycling and elliptical modalities were selected. There was no restriction regarding the duration of the protocol and the HIIT modality.

2.2.2 Type of Subjects

We decided to focus the review on adult subjects (age $\geq$ 18 years) because training adaptations and carbohydrate and lipid utilization in children and adolescents can be different. Subjects were not restricted by body mass index

Fig. 1 Systematic review process



(BMI), sex, pathologies, or ethnic origins, but high-level athletes were not included.

2.2.3 Outcome Measures

The primary outcome was total body fat mass (kg), while secondary outcomes were abdominal and visceral fat mass (with different units as grams, percentages, cm^2, or cm^3).

2.3 Data Collection or Data Synthesis

The first author (FM) extracted data from studies, with advice from NB on selection criteria. First, the title and abstract were screened, and then, if data were missing or interesting, the full text was analyzed; if it met our criteria, data were extracted. A request for missing data (total fat mass, abdominal fat mass, visceral fat mass, number of male/female subjects before and after the protocol, BMI, and age at the beginning of the study) was sent to corresponding authors when appropriate.

2.4 Statistical Analysis

After extraction, the data were compiled into software designed specifically for meta-analyses (Comprehensive Meta-Analysis, version 2; Biostat, Englewood, NJ, USA). Data included were sample size, and pre- and post-intervention values. The standardized mean differences (paired SMD) were calculated to determine Cohen's d for each study, and Hedges' g was used to account for potential bias in small sample sizes. Effect sizes (ESs) were calculated using a random-effects model (DerSimonian and Laird approach) that accounts for true variation in effects occurring from study to study and for random errors within a single study. The random-effects model was preferred to a fixed-effect model as certain experimental parameters had wide variation. The ESs were interpreted according to Cohen, i.e. <0.2 as trivial, 0.2–0.3 as small, 0.5 as moderate, and >0.8 as large [21]. A negative ES value indicates that exercise decreased outcomes, while a positive ES indicates that exercise increased outcomes. The I^2 index was used to measure heterogeneity, with 25, 50, and 75% indicating low, moderate, and high heterogeneity, respectively. In stratified analysis, we arbitrarily chose high-intensity levels as target intensities above 90% of PHR (and low intensity below 90% PHR). To test sensitivity and whether results were biased by a particular study, the analyses were conducted by excluding one study at a time. Funnel plots were used to assess publication bias. In the absence of bias, studies should be distributed evenly around the mean ES because of random sampling error. A meta-regression was performed to measure the impact of sex on variation of parameters.

3 Results

3.1 Study Selection

The search strategy identified 1156 articles from electronic databases, and six other articles were found manually. In total, 360 publications were excluded because of duplicate

Table 1 Characteristics of studies and subjects included in the review

Study	Number of subjects in HIIT group	Female/ male	Age (years)	BMI (kg/m^2)	Body composition measurements	Other
Ahmadizad et al. [46]	10	0/10	25.0 ± 1.0	27.7 ± 1.5	Impedance	Healthy sedentary and overweight men
Almenning et al. [47]	10	10/0	25.5 ± 5.0	26.1 ± 6.5	Impedance	Polycystic ovary syndrome
Arad et al. [48]	14	14/0	29.0 ± 4.0	32.5 ± 3.6	DXA VAT:MRI	Healthy overweight/obese women
Cassidy et al. [49]	14	NR	61.0 ± 9.0	31.0 ± 5.0	Plethysmography VAT:MRI	T2D
Coquart et al. [50]	10	10/0	52.0 ± 7.3	38.2 ± 7.9	Impedance	Obese women T2D
Coquart et al. [50]	10	10/0	51.2 ± 6.5	37.0 ± 3.8	Impedance	Obese women without T2D
Eimarieskandari et al. [51]	7	7/0	22.3 ± 0.9	29.2 ± 0.8	Impedance	Obese young girls
Fex et al. [24]	16	12/4	60.4 ± 6.1	34.6 ± 5.4	DXA	Pre-and T2D
Fisher et al. [52]	15	0/15	20.0 ± 1.5	30.0 ± 3.1	DXA	Sedentary overweight/obese men
Gahreman et al. [53]	12	0/12	26.1 ± 2.4	28.7 ± 2.8	DXA	Healthy volunteers
Gillen et al. [22]	8	8/0	27.0 ± 7.0	29.0 ± 3.0	DXA	Overweight/obese women—fed
Gillen et al. [22]	8	8/0	27.0 ± 9.0	29.0 ± 4.0	DXA	Overweight/obese women—fasted
Guadalupe-Grau et al. [54]	11	3/8	54.5 ± 8.7	32.8 ±1.9	DXA	Metabolic syndrome patients Postmenopausal women
Hallsworth et al. [55]	12	NR	54.0 ± 10.0	31.0 ± 4.0	Plethysmography VAT:MRI	Non-alcoholic fatty liver disease
Heydari et al. [56]	25	0/25	24.7 ± 4.8	28.4 ± 2.5	DXA VAT:CT scan	Inactive overweight men
Hornbuckle et al. [57]	16	16/0	32.1 ± 7.0	36.8 ± 4.3	DXA	Overweight and obese African–American women
Hutchison et al. [23]	20	20/0	29.5 ± 1.4	37.4 ± 1.5	DXA VAT:CT scan	Overweight women—polycystic ovary syndrome
Hutchison et al. [23]	14	14/0	35.0 ± 4.1	35.7 ± 4.9	DXA VAT:CT scan	Overweight women—no polycystic ovary syndrome
Hwang et al. [58]	17	11/6	64.8 ± 5.8	28.0 ± 4.5	DXA VAT:DXA	Healthy sedentary older adults
Karstoft et al. [59]	12	5/7	57.5 ± 8.3	29.0 ± 4.5	DXA VAT:MRI	T2D
Kong et al. [60]	11	10/0	19.8 ± 0.8	25.5 ± 2.1	DXA	Overweight and obese young women
Maillard et al. [16]	8	8/0	69.0 ± 2.8	32.6 ± 4.8	DXA VAT:CT scan	T2D postmenopausal
Martins et al. [61]	13	9/4	33.9 ± 7.8	33.2 ± 3.5	DXA	Sedentary obese individuals—protocol 1
Martins et al. [61]	9	5/4	34.1 ± 7.1	32.4 ± 2.9	DXA	Sedentary obese individuals—protocol 2
Matinhomaee et al. [62]	10	0/10	31.4 ± 10.2	29.2 ± 1.6	DXA	Healthy overweight men
Nikseresht et al. [63]	12	0/12	39.6 ± 3.7	30.0 ± 1.7	Skinfold	Healthy obese men
Panissa et al. [64]	11	11/0	28.4 ± 12.5	25.94 ± 4.1	Skinfold	Untrained women
Ramos et al. [65]	24	NR	57.0 ± 11.0	NR	DXA	Metabolic syndrome—protocol 1
Ramos et al. [65]	24	NR	57.0 ± 7.0	NR	DXA	Metabolic syndrome—protocol 2
Sandstad et al. [66]	7	7/0	32.4 ± 8.3	24.8 ± 4.9	Impedance	Rheumatic disease
Sasaki et al. [67]	12	0/12	NR	24.3 ± 0.7	Impedance Abdominal FM and VAT:MRI	Healthy sedentary men

Table 1 continued

Study	Number of subjects in HIIT group	Female/ male	Age (years)	BMI (kg/m^2)	Body composition measurements	Other
Sawyer et al. [25]	11	6/5	35.7 ± 8.2	37.4 ± 6.2	DXA	Obese adults
Schjerve et al. [68]	14	11/3	46.9 ± 8.2	36.6 ± 4.5	DXA	Obese adults
Shepherd et al. [69]	46	30/12	42±11.0	27.7±5.0	Impedance	Inactive overweight adults
Smith-Ryan et al. [70]	10	0/10	40.6 ± 12.1	28.4 ± 1.3	DXA	Overweight/obese men—protocol 1
Smith-Ryan et al. [70]	10	0/10	36.5 ± 12.3	32.1± 4.4	DXA	Overweight/obese men—protocol 2
Steckling et al. [71]	17	17/0	54.2 ± 6.2	30.7 ± 5.0	Impedance	Untrained metabolic syndrome women
Stensvold et al. [72]	11	4/7	49.9 ± 10.1	31.3 ± 4.3	DXA	Metabolic syndrome
Terada et al. [31]	8	4/4	62.0 ± 3.0	28.4± 4.1	DXA	T2D
Tjønna et al. [73]	13	0/13	41.8 ± 3.6	27.8 ± 1.8	DXA	Healthy overweight men—protocol 1
Tjønna et al. [73]	13	0/13	42.2 ± 2.4	27.0 ± 2.1	DXA	Healthy overweight men—protocol 2
Trapp et al. [15]	15	15/0	22.4 ± 2.7	24.4 ± 5.8	DXA	Healthy normal-weight women
Wallman et al. [74]	7	6/1	40.9 ± 11.7	31.4 ± 2.6	DXA	Overweight/obese adults
Zhang et al. [75]	14	14/0	21.0±1.0	25.8 ± 2.7	Impedance VAT:CT scan	Overweight women
Zhang et al. [76]	16	16/0	21.5 ± 1.7	25.4 ± 2.4	DXA VAT:CT scan	Overweight women
Ziemann et al. [77]	10	0/10	21.6 ± 1.1	24.5 ± 1.8	Impedance	Recreationally active males

Data are expressed as mean ± SD; in instances where the results were presented as mean ± SEM, SEM was converted to SD

BMI body mass index, *CT* computed tomography, *DXA* dual-energy X-ray absorptiometry, *FM* fat mass, *HIIT* high-intensity interval training, *MRI* magnetic resonance imaging, *NR* not reported, *SD* standard deviation, *SEM* standard error of the mean, *T2D* type 2 diabetes, *VAT* visceral adipose tissue

keywords or after title and/or abstract analysis. Of the remaining articles, 45 fulfilled our inclusion criteria. Among the 34 authors contacted for further details, 11 did not respond, therefore their publications were excluded. The final number of publications included in our meta-analysis was 39 (35 for total fat mass, 20 for abdominal fat mass, and 14 for visceral fat mass) (Fig. 1).

3.2 Subject Characteristics

Subject characteristics are summarized in Table 1. Overall, 617 subjects were included in the meta-analysis. Four studies gave no sex breakdown, and, in the remaining studies (n = 35) there were more women (321) than men (217). In accordance with the inclusion criteria, subjects were adults, with a mean age ranging from 19.8 ± 0.8 to 69 ± 2.8 years. All but two studies recruited overweight or obese subjects, whose BMI ranged from 25.4 ± 2.4 to 38.2 ± 7.9 kg/m^2. Some subjects had conditions that could have influenced the effects of physical activity: type 2 diabetes (n = 6), polycystic ovary syndrome (n = 2), hormonal state (menopause; n = 2), non-alcoholic fatty liver disease (n = 1), metabolic syndrome (n = 5), and rheumatic disease (n = 1).

3.3 High-Intensity Interval Training Program Characteristics

The HIIT programs are summarized in Table 2. Of the HIIT studies, 26 used cycling and 13 used running, with 4 studies offering a choice between the two. Only one study tested an elliptical modality. The most widely used protocol consisted of alternate 4 min at high intensity followed by 3 min of recovery (n = 12). Other programs used shorter times (8 s or 1 min) at high intensity. When specified, recovery was active in all but one study. The programs ranged in duration from 4 weeks to 6 months but generally lasted at least 12 weeks. Except in nine protocols, there were three HIIT sessions a week. Half of the studies used high-intensity training, defined in this meta-analysis as exercise at intensities above 90% PHR.

Table 2 HIIT protocol details

Study	Exercise modality	HIIT protocol	Durations	Frequency (per week)	Intensity[a] (high or low)
Ahmadizad et al. [46]	Running	8 × [1–1.5′ (90% v$\dot{V}O_2$max)/2–3′]	6 weeks	3	H
Almenning et al. [47]	Running or cycling	4 × [4′ (90–95% HRmax)/3′ (70% HRmax)] + 1/week: 10′: 1′ (100% of max. effort)/1′	10 weeks	3	H
Arad et al. [48]	Cycling	24′ [30–60 s (75–90% HRR)/180–210 (50% HRR)]	14 weeks	3	L
Cassidy et al. [49]	Cycling	5× [3′50 s (RPE: 16–17)/90 s passive R]	12 weeks	3	NR
Coquart et al. [50]	Cycling	32′: 2′ (80% VT)/2′ (120% VT)	10 weeks	3	L
Eimarieskandari et al. [51]	Running	25′: [4′ (80–90% $\dot{V}O_2$peak (85–95% of HRpeak))/3′ (50–60% of $\dot{V}O_2$peak (50–70% of HRpeak)) R]	8 weeks	3	L
Fex et al. [24]	Elliptical	20′: 30 s [(80–85% HRmax)/1′ 30 active R)]	12 weeks	3	L
Fisher et al. [52]	Cycling	20′: 4 × [4′ (15% MAPmax)/30 s (85% MAPmax)] + 2′ between sets at 15% MAPmax	6 weeks	3	L
Gahreman et al. [53]	Cycling	60 × [8 s (85–90% HRmax; 100 and 120 RPM/12s active R; 50–60 RPM)]	12 weeks	3	L
Gillen et al. [22]	Cycling	10 × [60 s (90% HRmax)/60s]	6 weeks	3	H
Gillen et al. [22]	Cycling	10× [60 s (90% HRmax)/60s]	6 weeks	3	H
Guadalupe-Grau et al. [54]	Cycling	4 × [4′ (90% HRmax)/3′ (70% HRmax) R]	6 months	3	H
Hallsworth et al. [55]	Cycling	5 × [2–3′ 50 (16–17 RPE)/3′ R)]	12 weeks	3	H
Heydari et al. [56]	Cycling	60 × [8 s (80–90% HRpeak)/12 s]	12 weeks	3	L
Hornbuckle et al. [57]	Running	32′: 3′ (60–70% HRmax)/1′ (80–90%) HRmax	16 weeks	3	L
Hutchison et al. [23]	Running	6–8 × [5′ (95–100% HRmax)/2 − 1′ R) + 1 session: 60′ at 75–85% HRmax (70% $\dot{V}O_2$max)	12 weeks	3	H
Hwang et al. [58]	Cycling	4 × [4′ (90% HRpeak)/3′ R (70% HRpeak)	8 weeks	4	H
Karstoft et al. [59]	Running	60′: 3′ (70% peak energy-expenditure rate)/3′ active R	16 weeks	5	L
Kong et al. [60]	Cycling	60 × [(8 s/12 s) R]	5 weeks	4	NR
Maillard et al. [16]	Cycling	20′: 60 × [8 s (77–83% HRmax/12s active R)]	16 weeks	2	L
Martins et al. [61]	Cycling	250 kcal: [8 s (85–90% HRmax)/12s) R]	12 weeks	3	L
Martins et al. [61]	Cycling	125 kcal: [8s (85–90%) HRmax/1s) R]	12 weeks	3	L
Matinhomaee et al. [62]	Running	6–12 × [60s (85–90% HRR)/60s (55–60% HRR)]	12 weeks	3	L
Nikseresht et al. [63]	Running	4 × [4′ (80–90% HRmax)/3′ (55–65% HRmax)]	12 weeks	3	L
Panissa et al. [64]	Cycling	15 × [1′ (90% HRmax)/30s (60% HRmax) R]	6 weeks	3	H
Ramos et al. [65]	Running or cycling	4 × [4′ (85–95% HRpeak)/3′ R (50–70% HRpeak)]	16 weeks	3	L
Ramos et al. [65]	Running or cycling	1 × [4′ (85–95% HRpeak)]	16 weeks	3	L
Sandstad et al. [66]	Cycling	4 × [4′ (85–95% HRmax)/3′ (70% HRmax)]	10 weeks	2	L
Sasaki et al. [67]	Cycling	10 × [1′ (85% $\dot{V}O_2$max)/30s R]	4 weeks	3	L

Table 2 continued

Study	Exercise modality	HIIT protocol	Durations	Frequency (per week)	Intensity[a] (high or low)
Sawyer et al. [25]	Cycling	10 × [1′ (90–95% HRmax)/1′ active R]	8 weeks	3	H
Schjerve et al. [68]	Running	4 × [4′ (85–95% HRmax)/3′ (50–60% HRmax)]	12 weeks	3	L
Shepherd et al. [69]	Cycling	18–25′: [15–60s (90% HRmax)/45–120 s active R]	10 weeks	3	H
Smith-Ryan et al. [70]	Cycling	5 × [2′ (80–100% $\dot{V}O_2$peak)/1′]	3 weeks	3	H
Smith-Ryan et al. [70]	Cycling	10′: 10 × [1′ (90% power peak/1′)]	3 weeks	3	H
Steckling et al. [71]	Running	4 × [4′ (90% HRmax)/3′ (70% HRmax) R]	12 weeks	3	H
Stensvold et al. [72]	Running	4 × [4′ (90–95% HRpeak)/3′ (70% HRpeak)	10 weeks	3	H
Terada et al. [31]	Running or cycling	30–60′ [1′ (100% $\dot{V}O_2$R)/3′ R (20% $\dot{V}O_2$R], but the 1 day per week HIIT group performed MICT	12 weeks	5	H
Tjønna et al. [73]	Running	1 × [4′ (90% HRmax)]	10 weeks	3	H
Tjønna et al. [73]	Running	4 × [4′ (90% HRmax)/3′ (70% HRmax)]	10 weeks	3	H
Trapp et al. [15]	Cycling	20′: 60 × (8 s/12 s)	15 weeks	3	NR
Wallman et al. [74]	Cycling	1′ (90% $\dot{V}O_2$peak)/2′ (30% $\dot{V}O_2$peak) R + diet education	8 weeks	4	H
Zhang et al. [75]	Running	4 × [4′ (85–95% HRpeak)/3′ (50–60% HRpeak) with 7′ rest between sets	12 weeks	4	L
Zhang et al. [76]	Cycling	300 kJ: 4′ (90% max)/3′ R)	12 weeks	3	H
Ziemann et al. [77]	Cycling	6 × [90s (80% p$\dot{V}O_2$max)/180 s R)]	6 weeks	3	L

H high, *HIIT* high-intensity interval training, *HRmax* maximum heart rate, *HRpeak* peak heart rate, *HRR* heart rate reserve, *L* low, *MAP* maximal aerobic power, *max.* maximum, *MICT* moderate-intensity continuous training, *NR* not reported, *p$\dot{V}O_2$max* power at $\dot{V}O_2$max, *R* recovery, *RPE* ratings of perceived exertion, *RPM* revolutions per minute, *$\dot{V}O_2$max* maximum oxygen concentration, *$\dot{V}O_2$peak* peak oxygen consumption, *$\dot{V}O_2$R* oxygen consumption reserve, *VT* ventilatory threshold, *v$\dot{V}O_2$* velocity corresponding to $\dot{V}O_2$max

[a]High intensity is defined as intensity superior to 90% peak heart rate

3.4 Body Composition Assessments

Most of the studies (n = 30) used a dual-energy X-ray absorptiometry (DXA; the 'gold standard' method) to determine whole-body fat mass. Others used less accurate and/or repeatable methods, such as impedance (n = 11), plethysmography (n = 2) or skinfold measurements (n = 2), of which the last was recognized as the least reliable. Computed tomography (CT) scan and magnetic resonance imaging (MRI) were widely used to assess abdominal or visceral fat mass. The most recent DXA scans can also measure abdominal fat mass in different anatomical regions [22, 23] and estimate visceral fat-mass content [24, 25].

3.5 Meta-Analysis

3.5.1 Total Fat Mass

As shown in Fig. 2a, HIIT resulted in a reduction of total fat mass (ES −0.2, 95% confidence interval [CI] −0.31 to −0.07, $I^2 = 0.0\%$) of approximately 2 kg. Stratified analysis of exercise modalities showed that running (ES −0.34, 95% CI −0.56 to −0.12, $I^2 = 0.0\%$) was more effective than cycling (ES −0.13, 95% CI −0.3 to 0.04, $I^2 = 0.0\%$) in decreasing total fat mass (Fig. 2b). The greatest HIIT effect was observed with protocols using high-intensity exercises (i.e. >90% PHR) [ES −0.21, 95% CI −0.38 to −0.04, $I^2 = 0.0\%$]; however, a trend was observed for low-intensity programs (ES −0.18, 95% CI

(a)

Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
	Statistics for each study				
Ahmadizad et al. 2015 [46]	-0.909	0.470	-1.829	0.012	0.053
Gahreman et al. 2016 [53]	0.125	0.409	-0.676	0.926	0.760
Gillen et al. 2013 (1) [22]	-0.076	0.500	-1.056	0.904	0.879
Gillen et al. 2013 (2) [22]	-0.059	0.500	-1.039	0.922	0.907
Guadalupe-Grau et al. 2017 [54]	-0.396	0.431	-1.240	0.447	0.357
Hallsworth et al. 2015 [55]	-0.240	0.410	-1.043	0.563	0.558
Heydari et al. 2012 [56]	-0.288	0.318	-0.911	0.335	0.366
Hornbuckle et al. 2017 [57]	0.024	0.426	-0.811	0.860	0.955
Hutchison et al. 2011 (1) [23]	-0.116	0.393	-0.886	0.653	0.767
Hutchison et al. 2011 (2) [23]	-0.247	0.502	-1.231	0.737	0.622
Hwang et al. 2016 [58]	-0.092	0.365	-0.808	0.624	0.801
Almenning et al. 2015 [47]	-0.064	0.500	-1.044	0.916	0.898
Karstoft et al. 2013 [59]	-0.333	0.411	-1.139	0.472	0.417
Kong et al. 2016 [60]	0.113	0.448	-0.764	0.990	0.801
Maillard et al. 2016 [16]	-0.098	0.500	-1.078	0.883	0.845
Matinhomaee et al. 2014 [62]	-1.525	0.508	-2.521	-0.529	0.003
Nikseresht et al. 2014 [63]	-1.015	0.434	-1.865	-0.165	0.019
Panissa et al. 2016 (1) [64]	-0.258	0.428	-1.097	0.581	0.547
Panissa et al. 2016 (2) [64]	-0.258	0.428	-1.097	0.581	0.547
Ramos et al. 2016 (1) [65]	-0.251	0.367	-0.970	0.467	0.493
Ramos et al. 2016 (2) [65]	-0.059	0.333	-0.713	0.594	0.859
Sawyer et al. 2016 [25]	-0.064	0.472	-0.988	0.860	0.892
Arad et al. 2015 [48]	-0.096	0.472	-1.021	0.828	0.838
Schjerve et al. 2008 [68]	-0.104	0.378	-0.845	0.637	0.784
Shepherd et al. 2015 [69]	-0.080	0.218	-0.507	0.348	0.715
Smith-Ryan et al. 2015 (1) [70]	-0.036	0.447	-0.912	0.841	0.936
Smith-Ryan et al. 2015 (2) [70]	0.015	0.447	-0.862	0.891	0.974
Steckling et al. 2016 [71]	0.019	0.343	-0.653	0.691	0.956
Stensvold et al. 2010 [72]	-0.250	0.428	-1.089	0.589	0.559
Terada et al. 2013 [31]	-0.226	0.502	-1.209	0.757	0.653
Tjønna et al. 2013 (1) [73]	-0.267	0.428	-1.106	0.573	0.534
Tjønna et al. 2013 (2) [73]	-0.290	0.394	-1.063	0.483	0.462
Trapp et al. 2008 [15]	-0.270	0.428	-1.109	0.570	0.529
Cassidy et al. 2016 [49]	-0.113	0.409	-0.913	0.688	0.783
Zhang et al. 2015 [75]	-0.388	0.412	-1.195	0.420	0.347
Zhang et al. 2017 [76]	-0.875	0.382	-1.624	-0.125	0.022
Ziemann et al. 2011 [77]	1.093	0.479	0.153	2.032	0.023
Coquart et al. 2008 (1) [50]	-0.110	0.448	-0.987	0.767	0.806
Coquart et al. 2008 (2) [50]	-0.250	0.449	-1.130	0.630	0.577
Eimarieskandari et al. 2012 [51]	0.064	0.535	-0.983	1.112	0.904
Fex et al. 2014 [24]	-0.009	0.354	-0.702	0.684	0.980
Fisher et al. 2015 [52]	-0.079	0.392	-0.848	0.690	0.840
Total	-0.189	0.063	-0.313	-0.066	0.003

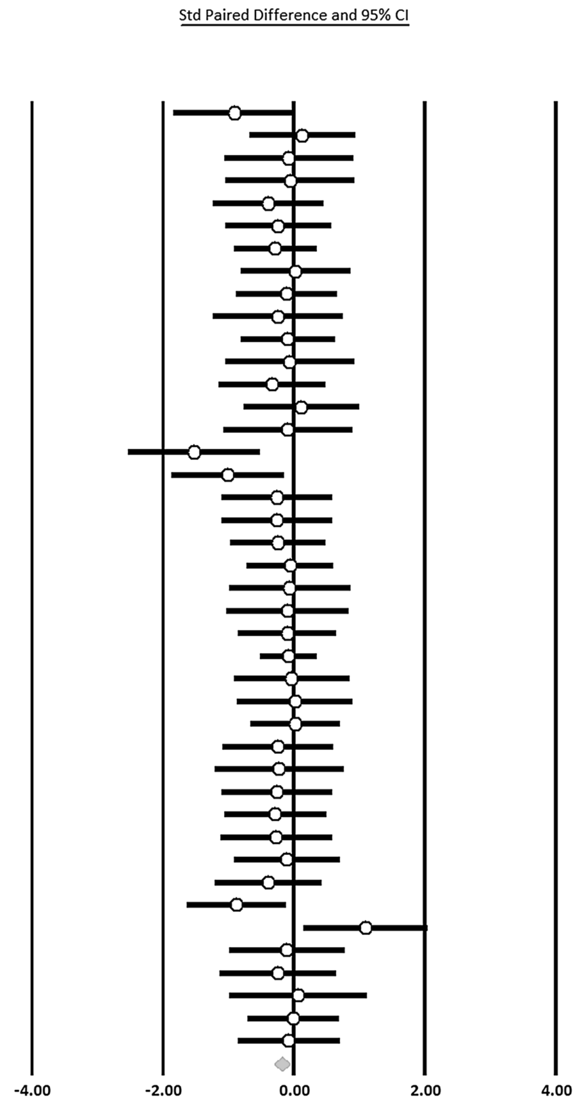


Fig. 2 Forest plot for the HIIT effect on (**a**) total fat mass (kg), (**b**) with stratified analysis of exercise modalities, (**c**) intensities, and (**d**) body weight. 1 and 2 represent the same study but different HIIT protocols. *CI* confidence interval, *HIIT* high-intensity interval training, *NR* not reported, *Std* standardized

-0.37 to 0.01, $I^2 = 14.5\%$) (Fig. 2c). Comparison of normal-weight and overweight/obese subjects showed that HIIT protocols decreased total fat mass only in patients with excess adiposity (ES 0.34, 95% CI -0.29 to 0.96, $I^2 = 77.7\%$; ES -0.21, 95% CI -0.34 to -0.08, $I^2 = 0.0\%$; respectively) (Fig. 2d). When normal-weight subjects were excluded from the analysis and only overweight/obese subjects were taken into consideration, significance persisted and was improved. There was no difference between male and female subjects in HIIT-induced fat-mass loss (p = 0.34).

3.5.2 Abdominal Fat Mass

Figure 3a shows that HIIT reduced abdominal fat mass (ES -0.19, 95% CI -0.32 to -0.05, $I^2 = 0.0\%$). The first stratified analysis of exercise modalities showed that, in contrast to results on total fat mass, cycling was more effective in decreasing abdominal fat mass (ES -0.24, 95% CI -0.40 to -0.08, $I^2 = 58.1\%$) than running (ES -0.05, 95% CI -0.41 to 0.31, $I^2 = 0.0\%$) (Fig. 3b). The second stratified analysis, involving method assessment, showed that CT scan (ES -0.33, 95% CI -0.56 to -0.1, $I^2 = 0.0\%$) detected more reductions in abdominal fat

(b)

Group by Modality	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Cycling	Arad et al. 2015 [48]	-0.096	0.472	-1.021	0.828	0.838
	Cassidy et al. 2016 [49]	-0.113	0.409	-0.913	0.688	0.783
	Coquart et al. 2008 (1) [50]	-0.110	0.448	-0.987	0.767	0.806
	Coquart et al. 2008 (2) [50]	-0.250	0.449	-1.130	0.630	0.577
	Fisher et al. 2015 [52]	-0.079	0.392	-0.848	0.690	0.840
	Gahreman et al. 2016 [53]	0.125	0.409	-0.676	0.926	0.760
	Gillen et al. 2013 (1) [22]	-0.076	0.500	-1.056	0.904	0.879
	Gillen et al. 2013 (2) [22]	-0.059	0.500	-1.039	0.922	0.907
	Guadalupe-Grau et al. 2017 [54]	-0.396	0.431	-1.240	0.447	0.357
	Hallsworth et al. 2015 [55]	-0.240	0.410	-1.043	0.563	0.558
	Heydari et al. 2012 [56]	-0.288	0.318	-0.911	0.335	0.366
	Hwang et al. 2016 [58]	-0.092	0.365	-0.808	0.624	0.801
	Kong et al. 2016 [60]	0.113	0.448	-0.764	0.990	0.801
	Maillard et al. 2016 [16]	-0.098	0.500	-1.078	0.883	0.845
	Panissa et al. 2016 (1) [64]	-0.258	0.428	-1.097	0.581	0.547
	Panissa et al. 2016 (2) [64]	-0.258	0.428	-1.097	0.581	0.547
	Sawyer et al. 2016 [25]	-0.064	0.472	-0.988	0.860	0.892
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.507	0.348	0.715
	Smith-Ryan et al. 2015 (1) [70]	-0.036	0.447	-0.912	0.841	0.936
	Smith-Ryan et al. 2015 (2) [70]	0.015	0.447	-0.862	0.891	0.974
	Trapp et al. 2008 [15]	-0.270	0.428	-1.109	0.570	0.529
	Zhang et al. 2017 [76]	-0.875	0.382	-1.624	-0.125	0.022
	Ziemann et al. 2011 [77]	1.093	0.479	0.153	2.032	0.023
	Subtotal	-0.125	0.084	-0.290	0.040	0.137
Elliptical	Fex et al. 2014 [24]	-0.009	0.354	-0.702	0.684	0.980
	Subtotal	-0.009	0.354	-0.702	0.684	0.980
Running	Ahmadizad et al. 2015 [46]	-0.909	0.470	-1.829	0.012	0.053
	Eimarieskandari et al. 2012 [51]	0.064	0.535	-0.983	1.112	0.904
	Hornbuckle et al. 2017 [57]	0.024	0.426	-0.811	0.860	0.955
	Hutchison et al. 2011 (1) [23]	-0.116	0.393	-0.886	0.653	0.767
	Hutchison et al. 2011 (2) [23]	-0.247	0.502	-1.231	0.737	0.622
	Karstoft et al. 2013 [59]	-0.333	0.411	-1.139	0.472	0.417
	Matinhomaee et al. 2014 [62]	-1.525	0.508	-2.521	-0.529	0.003
	Nikseresht et al. 2014 [63]	-1.015	0.434	-1.865	-0.165	0.019
	Schjerve et al. 2008 [68]	-0.104	0.378	-0.845	0.637	0.784
	Steckling et al. 2016 [71]	0.019	0.343	-0.653	0.691	0.956
	Stensvold et al. 2010 [72]	-0.250	0.428	-1.089	0.589	0.559
	Tjønna et al. 2013 (1) [73]	-0.267	0.428	-1.106	0.573	0.534
	Tjønna et al. 2013 (2) [73]	-0.290	0.394	-1.063	0.483	0.462
	Zhang et al. 2015 [75]	-0.388	0.412	-1.195	0.420	0.347
	Subtotal	-0.338	0.113	-0.560	-0.116	0.003
Running or cycling	Almenning et al. 2015 [47]	-0.064	0.500	-1.044	0.916	0.898
	Ramos et al. 2016 (1) [65]	-0.251	0.367	-0.970	0.467	0.493
	Ramos et al. 2016 (2) [65]	-0.059	0.333	-0.713	0.594	0.859
	Terada et al. 2013 [31]	-0.226	0.502	-1.209	0.757	0.653
	Subtotal	-0.146	0.202	-0.542	0.251	0.472

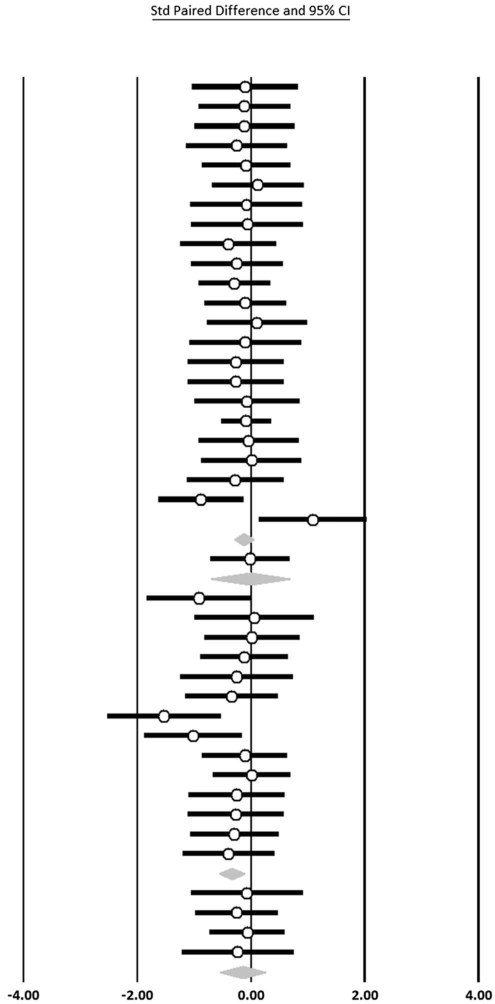


Fig. 2 continued

mass after HIIT than DXA scan (ES −0.12, 95% CI −0.30 to 0.06, $I^2 = 0.0\%$) and impedance (ES −0.08, 95% CI −0.51 to 0.35, $I^2 = 0.0\%$) (Fig. 3c). Low-intensity training reduced abdominal adiposity (ES −0.21, 95% CI −0.40 to −0.02, $I^2 = 0.0\%$), but no effect was observed at higher intensities (ES −0.18, 95% CI −0.41 to 0.05, $I^2 = 17.0\%$) (Fig. 3d). HIIT decreased abdominal fat mass in overweight/obese subjects only (ES −0.19, 95% CI −0.33 to −0.05, $I^2 = 0.0\%$) (Fig. 3e). When normal-weight subjects were excluded from the analysis and only overweight/obese subjects were taken into consideration, significance persisted and was improved. There was no difference between male and female subjects in HIIT-induced abdominal fat-mass loss ($p = 0.70$).

3.5.3 Visceral Fat Mass

As shown in Fig. 4a, HIIT decreased visceral fat mass (ES −0.24, 95% CI −0.44 to −0.04, $I^2 = 0.0\%$). A stratified analysis showed that only running reduced visceral fat mass (ES −0.44, 95% CI −0.86 to −0.02, $I^2 = 0.0\%$), while a trend was observed for cycling (ES −0.21, 95% CI −0.46 to 0.04, $I^2 = 0.0\%$) (Fig. 4b). Another stratified analysis showed that no study with DXA scan (ES −0.30, 95% CI −0.57 to 0.51, $I^2 = 0.0\%$) resulted in visceral fat-mass changes (ES −0.30, 95% CI −0.52 to −0.07, $I^2 = 0.0\%$) (Fig. 4c). As observed for abdominal fat mass, protocols using intensities <90% PHR decreased visceral fat mass (ES −0.31, 95% CI −0.57 to −0.05, $I^2 = 0.0\%$),

(c)

Group by Intensity	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
High	Ahmadizad et al. 2015 [46]	-0.909	0.470	-1.829	0.012	0.053
	Almenning et al. 2015 [47]	-0.064	0.500	-1.044	0.916	0.898
	Gillen et al. 2013 (1) [22]	-0.076	0.500	-1.056	0.904	0.879
	Gillen et al. 2013 (2) [22]	-0.059	0.500	-1.039	0.922	0.907
	Guadalupe-Grau et al. 2017 [54]	-0.396	0.431	-1.240	0.447	0.357
	Hallsworth et al. 2015 [55]	-0.240	0.410	-1.043	0.563	0.558
	Hutchison et al. 2011 (1) [23]	-0.116	0.393	-0.886	0.653	0.767
	Hutchison et al. 2011 (2) [23]	-0.247	0.502	-1.231	0.737	0.622
	Hwang et al. 2016 [58]	-0.092	0.365	-0.808	0.624	0.801
	Panissa et al. 2016 (1) [64]	-0.258	0.428	-1.097	0.581	0.547
	Panissa et al. 2016 (2) [64]	-0.258	0.428	-1.097	0.581	0.547
	Sawyer et al. 2016 [25]	-0.064	0.472	-0.988	0.860	0.892
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.507	0.348	0.715
	Smith-Ryan et al. 2015 (1) [70]	-0.036	0.447	-0.912	0.841	0.936
	Smith-Ryan et al. 2015 (2) [70]	0.015	0.447	-0.862	0.891	0.974
	Steckling et al. 2016 [71]	0.019	0.343	-0.653	0.691	0.956
	Stensvold et al. 2010 [72]	-0.250	0.428	-1.089	0.589	0.559
	Terada et al. 2013 [31]	-0.226	0.502	-1.209	0.757	0.653
	Tjønna et al. 2013 (1) [73]	-0.267	0.428	-1.106	0.573	0.534
	Tjønna et al. 2013 (2) [73]	-0.290	0.394	-1.063	0.483	0.462
	Zhang et al. 2017 [76]	-0.875	0.382	-1.624	-0.125	0.022
	Subtotal	-0.211	0.088	-0.384	-0.038	0.017
Low	Arad et al. 2015 [48]	-0.096	0.472	-1.021	0.828	0.838
	Coquart et al. 2008 (1) [50]	-0.110	0.448	-0.987	0.767	0.806
	Coquart et al. 2008 (2) [50]	-0.250	0.449	-1.130	0.630	0.577
	Eimarieskandari et al. 2012 [51]	0.064	0.535	-0.983	1.112	0.904
	Fex et al. 2014 [24]	-0.009	0.354	-0.702	0.684	0.980
	Fisher et al. 2015 [52]	-0.079	0.392	-0.848	0.690	0.840
	Gahreman et al. 2016 [53]	0.125	0.409	-0.676	0.926	0.760
	Heydari et al. 2012 [56]	-0.288	0.318	-0.911	0.335	0.366
	Hornbuckle et al. 2017 [57]	0.024	0.426	-0.811	0.860	0.955
	Karstoft et al. 2013 [59]	-0.333	0.411	-1.139	0.472	0.417
	Maillard et al. 2016 [16]	-0.098	0.500	-1.078	0.883	0.845
	Matinhomaee et al. 2014 [62]	-1.525	0.508	-2.521	-0.529	0.003
	Nikseresht et al. 2014 [63]	-1.015	0.434	-1.865	-0.165	0.019
	Ramos et al. 2016 (1) [65]	-0.251	0.367	-0.970	0.467	0.493
	Ramos et al. 2016 (2) [65]	-0.059	0.333	-0.713	0.594	0.859
	Schjerve et al. 2008 [68]	-0.104	0.378	-0.845	0.637	0.784
	Zhang et al. 2015 [75]	-0.388	0.412	-1.195	0.420	0.347
	Ziemann et al. 2011 [77]	1.093	0.479	0.153	2.032	0.023
	Subtotal	-0.177	0.097	-0.367	0.013	0.068
NR	Cassidy et al. 2016 [49]	-0.113	0.409	-0.913	0.688	0.783
	Kong et al. 2016 [60]	0.113	0.448	-0.764	0.990	0.801
	Trapp et al. 2008 [15]	-0.270	0.428	-1.109	0.570	0.529
	Subtotal	-0.096	0.247	-0.580	0.387	0.696

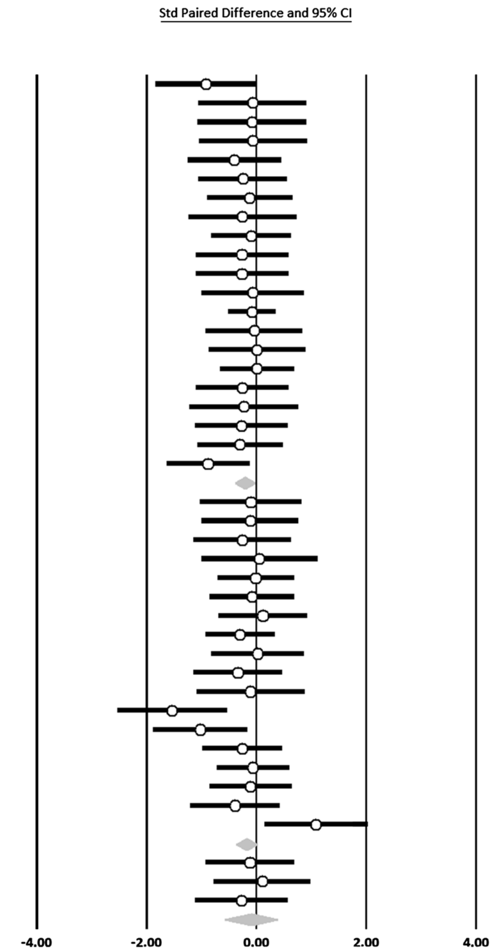


Fig. 2 continued

but not at an intensity above 90% PHR (ES -0.13, 95% CI -0.47 to 0.22, $I^2 = 0.0\%$) (Fig. 4d). HIIT was only successful in overweight/obese subjects (ES -0.26, 95% CI -0.47 to -0.05, $I^2 = 0.0\%$) (Fig. 4e). As reported for total and abdominal fat mass, when normal-weight subjects were excluded from the analysis and only overweight/obese subjects were taken into consideration, significance persisted and was improved. There was no difference between male and female subjects in HIIT-induced visceral fat-mass loss ($p = 0.69$).

4 Discussion

The present study is the first meta-analysis to investigate the effect of HIIT interventions on total, abdominal, and visceral adipose tissues in non-athlete subjects. The review involved 617 subjects (48% male and 52% female, mean age 38.8 ± 14.4 years, mean BMI 30.3 ± 4.0 kg/m^2) included in 39 studies (35 evaluating total fat mass, 19 abdominal fat mass, and 14 visceral fat mass). Only two studies were performed with normal-weight subjects, with the others involving overweight or obese patients. Our results showed that HIIT programs are effective in significantly reducing total, abdominal, and visceral fat mass in both males and females. These beneficial effects only occurred in overweight and obese subjects. Comparisons of running and cycling indicated that running is more effective in reducing total and visceral fat mass. High intensities (above 90% of PHR) seem more likely to reduce whole-body adiposity and lower intensities more successful in reducing abdominal and visceral fat mass. Finally, our analysis demonstrated that only CT scan or MRI studies showed significant abdominal and/or visceral fat-mass changes after HIIT interventions.

The HIIT modality is well tolerated, safe, and is a time-efficient strategy for improving patient health [26]; however, it should not be proposed to patients with

(d)

Group by Body weight	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Normal weight	Trapp et al. 2008 [15]	-0.270	0.428	-1.109	0.570	0.529
	Ziemann et al. 2011 [77]	1.093	0.479	0.153	2.032	0.023
	Subtotal	0.335	0.319	-0.291	0.961	0.294
Overweight-Obese	Ahmadizad et al. 2015 [46]	-0.909	0.470	-1.829	0.012	0.053
	Almenning et al. 2015 [47]	-0.064	0.500	-1.044	0.916	0.898
	Arad et al. 2015 [48]	-0.096	0.472	-1.021	0.828	0.838
	Cassidy et al. 2016 [49]	-0.113	0.409	-0.913	0.688	0.783
	Coquart et al. 2008 (1) [50]	-0.110	0.448	-0.987	0.767	0.806
	Coquart et al. 2008 (2) [50]	-0.250	0.449	-1.130	0.630	0.577
	Eimarieskandari et al. 2012 [51]	0.064	0.535	-0.983	1.112	0.904
	Fex et al. 2014 [24]	-0.009	0.354	-0.702	0.684	0.980
	Fisher et al. 2015 [52]	-0.079	0.392	-0.848	0.690	0.840
	Gahreman et al. 2016 [53]	0.125	0.409	-0.676	0.926	0.760
	Gillen et al. 2013 (1) [22]	-0.076	0.500	-1.056	0.904	0.879
	Gillen et al. 2013 (2) [22]	-0.059	0.500	-1.039	0.922	0.907
	Guadalupe-Grau et al. 2017 [54]	-0.396	0.431	-1.240	0.447	0.357
	Hallsworth et al. 2015 [55]	-0.240	0.410	-1.043	0.563	0.558
	Heydari et al. 2012 [56]	-0.288	0.318	-0.911	0.335	0.366
	Hornbuckle et al. 2017 [57]	0.024	0.426	-0.811	0.860	0.955
	Hutchison et al. 2011 (1) [23]	-0.116	0.393	-0.886	0.653	0.767
	Hutchison et al. 2011 (2) [23]	-0.247	0.502	-1.231	0.737	0.622
	Hwang et al. 2016 [58]	-0.092	0.365	-0.808	0.624	0.801
	Karstoft et al. 2013 [59]	-0.333	0.411	-1.139	0.472	0.417
	Kong et al. 2016 [60]	0.113	0.448	-0.764	0.990	0.801
	Maillard et al. 2016 [16]	-0.098	0.500	-1.078	0.883	0.845
	Matinhomaee et al. 2014 [62]	-1.525	0.508	-2.521	-0.529	0.003
	Nikseresht et al. 2014 [63]	-1.015	0.434	-1.865	-0.165	0.019
	Panissa et al. 2016 (1) [64]	-0.258	0.428	-1.097	0.581	0.547
	Panissa et al. 2016 (2) [64]	-0.258	0.428	-1.097	0.581	0.547
	Ramos et al. 2016 (1) [65]	-0.251	0.367	-0.970	0.467	0.493
	Ramos et al. 2016 (2) [65]	-0.059	0.333	-0.713	0.594	0.859
	Sawyer et al. 2016 [25]	-0.064	0.472	-0.988	0.860	0.892
	Schjerve et al. 2008 [68]	-0.104	0.378	-0.845	0.637	0.784
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.507	0.348	0.715
	Smith-Ryan et al. 2015 (1) [70]	-0.036	0.447	-0.912	0.841	0.936
	Smith-Ryan et al. 2015 (2) [70]	0.015	0.447	-0.862	0.891	0.974
	Steckling et al. 2016 [71]	0.019	0.343	-0.653	0.691	0.956
	Stensvold et al. 2010 [72]	-0.250	0.428	-1.089	0.589	0.559
	Terada et al. 2013 [31]	-0.226	0.502	-1.209	0.757	0.653
	Tjønna et al. 2013 (1) [73]	-0.267	0.428	-1.106	0.573	0.534
	Tjønna et al. 2013 (2) [73]	-0.290	0.394	-1.063	0.483	0.462
	Zhang et al. 2015 [75]	-0.388	0.412	-1.195	0.420	0.347
	Zhang et al. 2017 [76]	-0.875	0.382	-1.624	-0.125	0.022
	Subtotal	-0.210	0.064	-0.336	-0.084	0.001

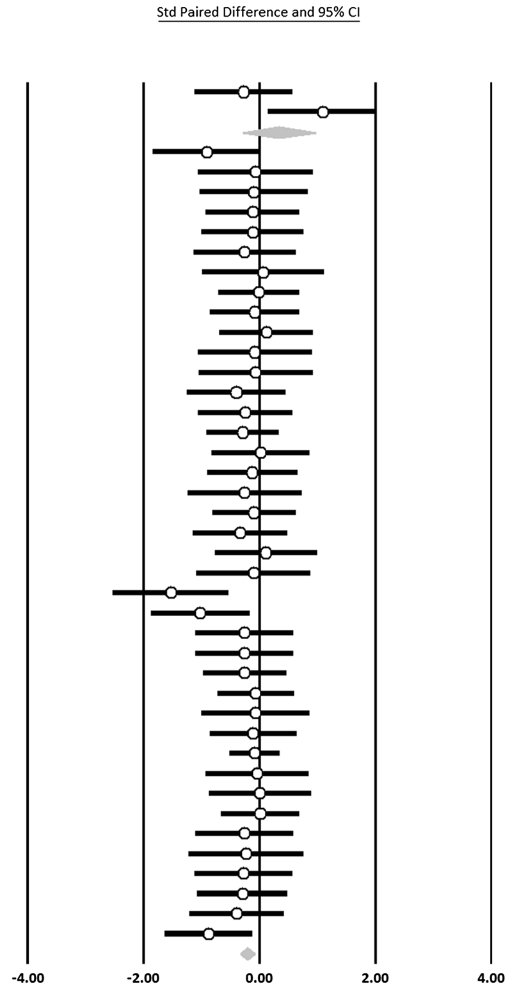


Fig. 2 continued

uncontrolled type 2 diabetes or hypertension, or after recent cardiac events [17]. For these patients, and for individuals with a high level of sedentary life/inactivity, the American College of Sports Medicine (ACSM) recommends reaching a 'base fitness level' by 20- to 60-min sessions, three to five times prior to beginning any training program [7].

The primary finding of our analysis is that HIIT significantly reduces whole-body fat mass. This result is in agreement with the results of recent reviews by Wewege et al. [14], who reported a mean loss of approximately 2 kg after HIIT protocols, and Keating et al. [13], who reported a loss of approximately 6% of body weight. The main objective of these two meta-analyses was to compare the effects of HIIT versus MICT, or HIIT/SIT versus MICT, on whole-body fat mass; however, owing to the comparative nature of their reviews, the number of studies analyzed was much smaller ($n = 13$ and $n = 28$, respectively) than in our meta-analysis ($n = 35$). In addition, these reviews did not perform a meta-analysis of HIIT-induced abdominal and/or visceral fat-mass changes and included no specific results regarding the effects of sex and body adiposity.

HIIT or SIT protocols were *prima facie* used in high-level athletes for increasing $\dot{V}O_2$max and/or reducing the percentage of fat mass before a competition [27, 28]. The use of HIIT interventions in overweight/obese patients is more recent and interest in HIIT-induced fat-mass loss in normal-weight subjects is still limited. This probably explains the small number of studies ($n = 2$) in our meta-analysis dealing with normal-weight patients. With these limitations (only two HIIT modalities, 21 subjects tested), no significant effect emerged from our analysis of HIIT-induced total fat-mass loss in this population. The sensitivity test performed (excluding normal-weight subjects) confirmed the finding that HIIT is more likely to decrease

(a)

Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Fex et al. 2014 (1) [24]	0.000	0.354	-0.693	0.693	1.000
Fex et al. 2014 (2) [24]	-0.074	0.343	-0.747	0.598	0.829
Gahreman et al. 2016 [53]	-0.143	0.409	-0.944	0.658	0.727
Gillen et al. 2013 (1) [22]	-0.094	0.500	-1.075	0.886	0.850
Gillen et al. 2013 (2) [22]	-0.189	0.501	-1.171	0.794	0.707
Heydari et al. 2012 (1) [56]	-0.366	0.319	-0.991	0.259	0.251
Heydari et al. 2012 (2) [56]	-0.250	0.317	-0.872	0.372	0.431
Heydari et al. 2012 (3) [56]	-0.260	0.318	-0.883	0.362	0.412
Heydari et al. 2012 (4) [56]	-0.219	0.317	-0.840	0.403	0.491
Hornbuckle et al. 2017 [57]	-0.026	0.426	-0.862	0.810	0.951
Hutchison et al. 2011 (1) [23]	-0.179	0.448	-1.057	0.699	0.690
Hutchison et al. 2011 (2) [23]	-0.214	0.501	-1.197	0.769	0.669
kong et al. 2016 (1) [60]	0.094	0.447	-0.783	0.971	0.834
kong et al. 2016 (2) [60]	0.000	0.447	-0.877	0.877	1.000
Maillard et al. 2016 (1) [16]	-0.276	0.502	-1.260	0.709	0.583
Maillard et al. 2016 (2) [16]	-0.320	0.503	-1.306	0.667	0.525
Martins et al. 2016 (1) [61]	-0.123	0.393	-0.892	0.647	0.754
Martins et al. 2016 (2) [61]	-0.203	0.473	-1.130	0.723	0.667
Matinhomaee et al. 2014 [62]	-1.242	0.488	-2.199	-0.284	0.011
Ramos et al 2016 (2) [65]	-0.051	0.333	-0.705	0.602	0.878
Ramos et al. 2016 (1) [65]	-0.203	0.366	-0.921	0.514	0.579
Sasaki et al. 2014 [67]	0.078	0.408	-0.723	0.878	0.849
Sawyer et al. 2016 [25]	-0.148	0.472	-1.073	0.777	0.754
Shepherd et al. 2015 [69]	-0.080	0.218	-0.508	0.348	0.714
Terada et al. 2013 [31]	-0.282	0.502	-1.267	0.702	0.574
Tjønna et al. 2013 (1) [73]	0.000	0.426	-0.836	0.836	1.000
Tjønna et al. 2013 (2) [73]	0.942	0.413	0.132	1.752	0.023
Trapp et al. 2008 (1) [15]	-0.234	0.428	-1.072	0.605	0.585
Trapp et al. 2008 (2) [15]	-0.307	0.429	-1.147	0.534	0.474
Wallman et al. 2009 [74]	-0.663	0.549	-1.739	0.413	0.227
Zhang et al. 2017 (1) [76]	-0.750	0.378	-1.490	-0.010	0.047
Zhang et al. 2017 (2) [76]	-0.762	0.378	-1.503	-0.021	0.044
Total	-0.188	0.069	-0.324	-0.053	0.007

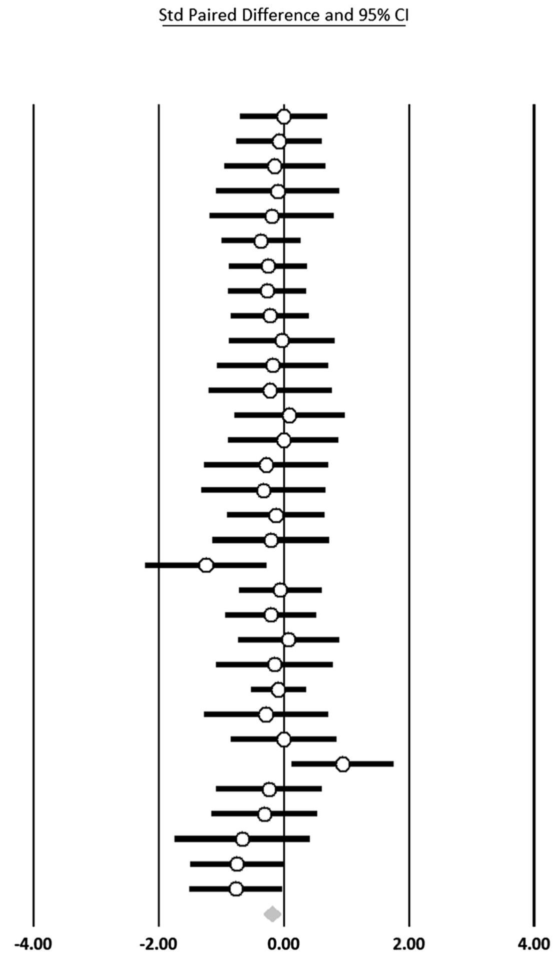


Fig. 3 Forest plot for the HIIT effect on (**a**) abdominal fat mass, (**b**) with stratified analysis of exercise modalities, (**c**) methods of measuring body composition, (**d**) intensities, and (**e**) body weight. 1–4 represent the same study but different HIIT protocols. *CI* confidence interval, *CT* computed tomography, *DXA* dual-energy X-ray absorptiometry, *HIIT* high-intensity interval training, *MRI* magnetic resonance imaging, *NR* not reported, *Std* standardized

total fat-mass loss in overweight/obese subjects (overall: $p = 0.003$; overweight/obese subjects only: $p = 0.001$).

The second finding was the impact of HIIT programs on abdominal and visceral fat mass. Documented reports have shown that effective abdominal/visceral fat-loss strategies should include a hypocaloric diet or physical activity, or both [29]; however, the best results are obtained when the two strategies are combined [6]. The recent meta-analysis of Verheggen et al. [30] confirmed that diet or training alone can significantly alter visceral fat mass, but generally to a greater extent overall with exercise ($p = 0.08$). In this review [30], 117 studies (4815 subjects) were included and, in the absence of weight loss, the authors showed that exercise is still related to a 6.1% decrease in visceral adipose tissue. In the literature, of the 12 publications that compared the effects of HIIT versus MICT on abdominal/visceral fat-mass loss, only 6 reported an effect of HIIT or a greater effect of this modality, 3 reported an equivalent effect, and 3 did not find any significant difference between the two modalities. In our review, we separately assessed the effects of HIIT on abdominal (18 studies) and visceral (14 studies) adipose tissues using different methods, including DXA, CT scan, and MRI. One drawback of the present meta-analysis with regard to the assessment of abdominal fat was the region chosen by the authors to represent ‘abdominal adiposity’. Three areas, designated ‘abdominal’ ($n = 14$), ‘trunk’ ($n = 12$), or ‘android region or area’ ($n = 6$), were used in the publication analyzed, but most of the time represented different anatomic regions. In relation to visceral fat mass, the data were more homogeneous since most of the studies analyzed the L4-L5 junction. Our results showed that HIIT significantly reduced

(b)

Group by Modality	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Cycling	Gahreman et al. 2016 [53]	-0.143	0.409	-0.944	0.658	0.727
	Gillen et al. 2013 (1) [22]	-0.094	0.500	-1.075	0.886	0.850
	Gillen et al. 2013 (2) [22]	-0.189	0.501	-1.171	0.794	0.707
	Heydari et al. 2012 (1) [56]	-0.366	0.319	-0.991	0.259	0.251
	Heydari et al. 2012 (2) [56]	-0.250	0.317	-0.872	0.372	0.431
	Heydari et al. 2012 (3) [56]	-0.260	0.318	-0.883	0.362	0.412
	Heydari et al. 2012 (4) [56]	-0.219	0.317	-0.840	0.403	0.491
	kong et al. 2016 (1) [60]	0.094	0.447	-0.783	0.971	0.834
	kong et al. 2016 (2) [60]	0.000	0.447	-0.877	0.877	1.000
	Maillard et al. 2016 (1) [16]	-0.276	0.502	-1.260	0.709	0.583
	Maillard et al. 2016 (2) [16]	-0.320	0.503	-1.306	0.667	0.525
	Martins et al. 2016 (1) [61]	-0.123	0.393	-0.892	0.647	0.754
	Martins et al. 2016 (2) [61]	-0.203	0.473	-1.130	0.723	0.667
	Sasaki et al. 2014 [67]	0.078	0.408	-0.723	0.878	0.849
	Sawyer et al. 2016 [25]	-0.148	0.472	-1.073	0.777	0.754
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.508	0.348	0.714
	Trapp et al. 2008 (1) [15]	-0.234	0.428	-1.072	0.605	0.585
	Trapp et al. 2008 (2) [15]	-0.307	0.429	-1.147	0.534	0.474
	Wallman et al. 2009 [74]	-0.663	0.549	-1.739	0.413	0.227
	Zhang et al. 2017 (1) [76]	-0.750	0.378	-1.490	-0.010	0.047
	Zhang et al. 2017 (2) [76]	-0.762	0.378	-1.503	-0.021	0.044
	Subtotal	-0.239	0.084	-0.404	-0.075	0.004
Elliptical	Fex et al. 2014 (1) [24]	0.000	0.354	-0.693	0.693	1.000
	Fex et al. 2014 (2) [24]	-0.074	0.343	-0.747	0.598	0.829
	Subtotal	-0.038	0.246	-0.521	0.444	0.877
Running	Hornbuckle et al. 2017 [57]	-0.026	0.426	-0.862	0.810	0.951
	Hutchison et al. 2011 (1) [23]	-0.179	0.448	-1.057	0.699	0.690
	Hutchison et al. 2011 (2) [23]	-0.214	0.501	-1.197	0.769	0.669
	Matinhomaee et al. 2014 [62]	-1.242	0.488	-2.199	-0.284	0.011
	Tjønna et al. 2013 (1) [73]	0.000	0.426	-0.836	0.836	1.000
	Tjønna et al. 2013 (2) [73]	0.942	0.413	0.132	1.752	0.023
	Subtotal	-0.053	0.183	-0.410	0.305	0.773
Running or cycling	Ramos et al 2016 (2) [65]	-0.051	0.333	-0.705	0.602	0.878
	Ramos et al. 2016 (1) [65]	-0.203	0.366	-0.921	0.514	0.579
	Terada et al. 2013 [31]	-0.282	0.502	-1.267	0.702	0.574
	Subtotal	-0.152	0.221	-0.585	0.282	0.493

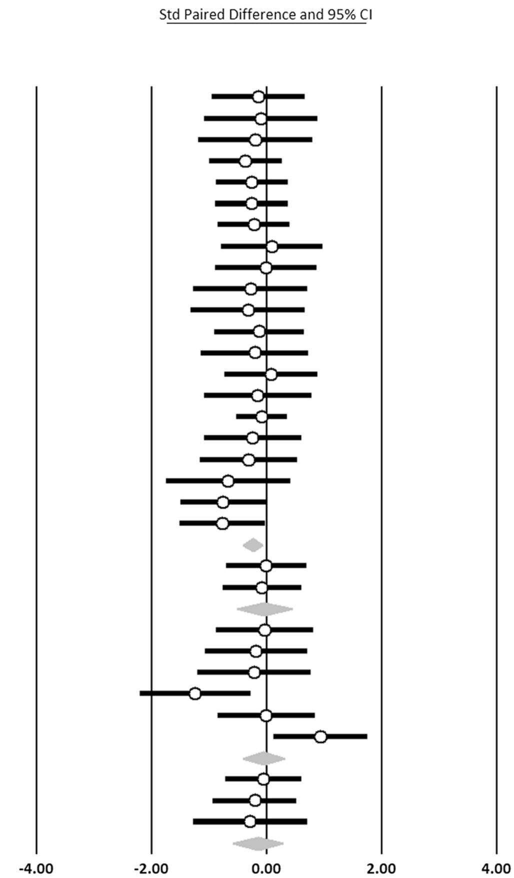


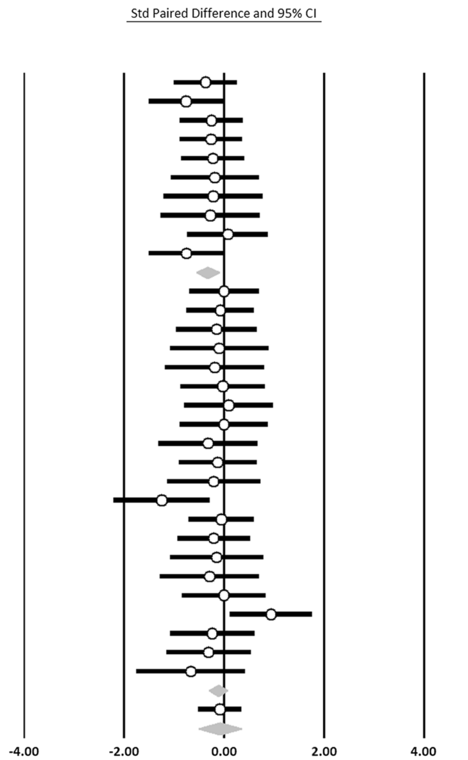
Fig. 3 continued

abdominal (p = 0.007) and visceral (p = 0.018) fat mass, with no difference between males and females. When the statistical analysis was performed in only normal-weight subjects, the results did not show any effect of HIIT on abdominal/visceral adipose tissue. However, the analyses of abdominal and visceral fat mass related to only three and two publications, respectively. In conclusion, HIIT is an efficient method to reduce central adiposity, at least in overweight/obese patients, which suggests that it could favorably contribute to decreasing the risks of cardiovascular disease. Furthermore, the effects of HIIT, when compared with those of MICT, seem more likely to decrease abdominal/visceral adipose tissue than endurance training [16, 31]. However, additional research is required to fully understand the mechanisms underlying abdominal/visceral fat reduction induced by HIIT programs.

The third finding to emerge from this meta-analysis was that running is more effective than cycling in reducing total and visceral fat mass, and that cycling is more successful in decreasing total abdominal fat mass. Physiological, metabolic and ergogenic responses differ between running and cycling. Running promotes larger muscle mass than cycling and the type of muscle contraction during running (concentric and eccentric) contributes to greater fat oxidation at the same relative intensity [32, 33]. In addition, excess post-exercise oxygen consumption (EPOC) is greater (+ 37%) after a running session than after a cycling session, as shown in the study by Cunha et al. comparing HIIT and MICT treadmill protocol in overweight men (exercises performed at 75% of oxygen uptake reserve, running session corresponding to 400 kcal, and interval training including two series of 200 kcal) [34]. In addition, plasma lactate concentrations are higher in cycling [34], which reflects greater carbohydrate utilization [33]. Together, these results could explain the greater effect of running on decreasing total fat mass. However, it is more difficult to explain the impact of running and cycling on abdominal and visceral adipose tissues. One of the potential explanations could be the release of catecholamines. During high-intensity exercise (i.e. > 65% $\dot{V}O_2$max),

(c)

Group by: Methods of measuring body composition	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
CT-scan or MRI	Heydari et al. 2012 (1) [56]	-0.366	0.319	-0.991	0.259	0.251
	Zhang et al. 2017 (2) [76]	-0.762	0.378	-1.503	-0.021	0.044
	Heydari et al. 2012 (2) [56]	-0.250	0.317	-0.872	0.372	0.431
	Heydari et al. 2012 (3) [56]	-0.260	0.318	-0.883	0.362	0.412
	Heydari et al. 2012 (4) [56]	-0.219	0.317	-0.840	0.403	0.491
	Hutchison et al. 2011 (1) [23]	-0.179	0.448	-1.057	0.699	0.690
	Hutchison et al. 2011 (2) [23]	-0.214	0.501	-1.197	0.769	0.669
	Maillard et al. 2016 (1) [16]	-0.276	0.502	-1.260	0.709	0.583
	Sasaki et al. 2014 [67]	0.078	0.408	-0.723	0.878	0.849
	Zhang et al. 2017 (1) [76]	-0.750	0.378	-1.490	-0.010	0.047
	Subtotal	-0.328	0.117	-0.558	-0.098	0.005
DXA	Fex et al. 2014 (1) [24]	0.000	0.354	-0.693	0.693	1.000
	Fex et al. 2014 (2) [24]	-0.074	0.343	-0.747	0.598	0.829
	Gahreman et al. 2016 [53]	-0.143	0.409	-0.944	0.658	0.727
	Gillen et al. 2013 (1) [22]	-0.094	0.500	-1.075	0.886	0.850
	Gillen et al. 2013 (2) [22]	-0.189	0.501	-1.171	0.794	0.707
	Hornbuckle et al. 2017 [57]	-0.026	0.426	-0.862	0.810	0.951
	kong et al. 2016 (1) [60]	0.094	0.447	-0.783	0.971	0.834
	kong et al. 2016 (2) [60]	0.000	0.447	-0.877	0.877	1.000
	Maillard et al. 2016 (2) [16]	-0.320	0.503	-1.306	0.667	0.525
	Martins et al. 2016 (1) [61]	-0.123	0.393	-0.892	0.647	0.754
	Martins et al. 2016 (2) [61]	-0.203	0.473	-1.130	0.723	0.667
	Matinhomaee et al. 2014 [62]	-1.242	0.488	-2.199	-0.284	0.011
	Ramos et al 2016 (2) [65]	-0.051	0.333	-0.705	0.602	0.878
	Ramos et al. 2016 (1) [65]	-0.203	0.366	-0.921	0.514	0.579
	Sawyer et al. 2016 [25]	-0.148	0.472	-1.073	0.777	0.754
	Terada et al. 2013 [31]	-0.282	0.502	-1.267	0.702	0.574
	Tjønna et al. 2013 (1) [73]	0.000	0.426	-0.836	0.836	1.000
	Tjønna et al. 2013 (2) [73]	0.942	0.413	0.132	1.752	0.023
	Trapp et al. 2008 (1) [15]	-0.234	0.428	-1.072	0.605	0.585
	Trapp et al. 2008 (2) [15]	-0.307	0.429	-1.147	0.534	0.474
	Wallman et al. 2009 [74]	-0.663	0.549	-1.739	0.413	0.227
	Subtotal	-0.120	0.093	-0.302	0.062	0.197
Impedance	Shepherd et al. 2015 [69]	-0.080	0.218	-0.508	0.348	0.714
	Subtotal	-0.080	0.218	-0.508	0.348	0.714



(d)

Group by: Intensity	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
High	Gillen et al. 2013 (1) [22]	-0.094	0.500	-1.075	0.886	0.850
	Gillen et al. 2013 (2) [22]	-0.189	0.501	-1.171	0.794	0.707
	Hutchison et al. 2011 (1) [23]	-0.179	0.448	-1.057	0.699	0.690
	Hutchison et al. 2011 (2) [23]	-0.214	0.501	-1.197	0.769	0.669
	Sawyer et al. 2016 [25]	-0.148	0.472	-1.073	0.777	0.754
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.508	0.348	0.714
	Terada et al. 2013 [31]	-0.282	0.502	-1.267	0.702	0.574
	Tjønna et al. 2013 (1) [73]	0.000	0.426	-0.836	0.836	1.000
	Tjønna et al. 2013 (2) [73]	0.942	0.413	0.132	1.752	0.023
	Wallman et al. 2009 [74]	-0.663	0.549	-1.739	0.413	0.227
	Zhang et al. 2017 (1) [76]	-0.750	0.378	-1.490	-0.010	0.047
	Zhang et al. 2017 (2) [76]	-0.762	0.378	-1.503	-0.021	0.044
	Subtotal	-0.181	0.115	-0.408	0.045	0.116
Low	Fex et al. 2014 (1) [24]	0.000	0.354	-0.693	0.693	1.000
	Fex et al. 2014 (2) [24]	-0.074	0.343	-0.747	0.598	0.829
	Gahreman et al. 2016 [53]	-0.143	0.409	-0.944	0.658	0.727
	Heydari et al. 2012 (1) [56]	-0.366	0.319	-0.991	0.259	0.251
	Heydari et al. 2012 (2) [56]	-0.250	0.317	-0.872	0.372	0.431
	Heydari et al. 2012 (3) [56]	-0.260	0.318	-0.883	0.362	0.412
	Heydari et al. 2012 (4) [56]	-0.219	0.317	-0.840	0.403	0.491
	Hornbuckle et al. 2017 [57]	-0.026	0.426	-0.862	0.810	0.951
	Maillard et al. 2016 (1) [16]	-0.276	0.502	-1.260	0.709	0.583
	Maillard et al. 2016 (2) [16]	-0.320	0.503	-1.306	0.667	0.525
	Martins et al. 2016 (1) [61]	-0.123	0.393	-0.892	0.647	0.754
	Martins et al. 2016 (2) [61]	-0.203	0.473	-1.130	0.723	0.667
	Matinhomaee et al. 2014 [62]	-1.242	0.488	-2.199	-0.284	0.011
	Ramos et al 2016 (2) [65]	-0.051	0.333	-0.705	0.602	0.878
	Ramos et al. 2016 (1) [65]	-0.203	0.366	-0.921	0.514	0.579
	Sasaki et al. 2014 [67]	0.078	0.408	-0.723	0.878	0.849
	Subtotal	-0.205	0.094	-0.390	-0.021	0.029
NR	kong et al. 2016 (1) [60]	0.094	0.447	-0.783	0.971	0.834
	kong et al. 2016 (2) [60]	0.000	0.447	-0.877	0.877	1.000
	Trapp et al. 2008 (1) [15]	-0.234	0.428	-1.072	0.605	0.585
	Trapp et al. 2008 (2) [15]	-0.307	0.429	-1.147	0.534	0.474
	Subtotal	-0.119	0.219	-0.547	0.310	0.588

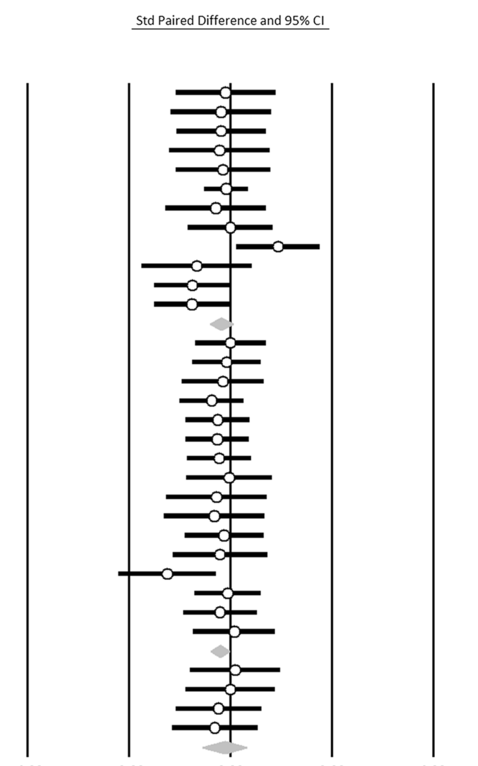


Fig. 3 continued

(e)

Group by Body weight	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Normal weight	Sasaki et al. 2014 [67]	0.078	0.408	-0.723	0.878	0.849
	Trapp et al. 2008 (1) [15]	-0.234	0.428	-1.072	0.605	0.585
	Trapp et al. 2008 (2) [15]	-0.307	0.429	-1.147	0.534	0.474
	Subtotal	-0.147	0.243	-0.624	0.330	0.546
Overweight-Obese	Fex et al. 2014 (1) [24]	0.000	0.354	-0.693	0.693	1.000
	Fex et al. 2014 (2) [24]	-0.074	0.343	-0.747	0.598	0.829
	Gahreman et al. 2016 [53]	-0.143	0.409	-0.944	0.658	0.727
	Gillen et al. 2013 (1) [22]	-0.094	0.500	-1.075	0.886	0.850
	Gillen et al. 2013 (2) [22]	-0.189	0.501	-1.171	0.794	0.707
	Heydari et al. 2012 (1) [56]	-0.366	0.319	-0.991	0.259	0.251
	Heydari et al. 2012 (2) [56]	-0.250	0.317	-0.872	0.372	0.431
	Heydari et al. 2012 (3) [56]	-0.260	0.318	-0.883	0.362	0.412
	Heydari et al. 2012 (4) [56]	-0.219	0.317	-0.840	0.403	0.491
	Hornbuckle et al. 2017 [57]	-0.026	0.426	-0.862	0.810	0.951
	Hutchison et al. 2011 (1) [23]	-0.179	0.448	-1.057	0.699	0.690
	Hutchison et al. 2011 (2) [23]	-0.214	0.501	-1.197	0.769	0.669
	kong et al. 2016 (1) [60]	0.094	0.447	-0.783	0.971	0.834
	kong et al. 2016 (2) [60]	0.000	0.447	-0.877	0.877	1.000
	Maillard et al. 2016 (1) [16]	-0.276	0.502	-1.260	0.709	0.583
	Maillard et al. 2016 (2) [16]	-0.320	0.503	-1.306	0.667	0.525
	Martins et al. 2016 (1) [61]	-0.123	0.393	-0.892	0.647	0.754
	Martins et al. 2016 (2) [61]	-0.203	0.473	-1.130	0.723	0.667
	Matinhomaee et al. 2014 [62]	-1.242	0.488	-2.199	-0.284	0.011
	Ramos et al 2016 (2) [65]	-0.051	0.333	-0.705	0.602	0.878
	Ramos et al. 2016 (1) [65]	-0.203	0.366	-0.921	0.514	0.579
	Sawyer et al. 2016 [25]	-0.148	0.472	-1.073	0.777	0.754
	Shepherd et al. 2015 [69]	-0.080	0.218	-0.508	0.348	0.714
	Terada et al. 2013 [31]	-0.282	0.502	-1.267	0.702	0.574
	Tjønna et al. 2013 (1) [73]	0.000	0.426	-0.836	0.836	1.000
	Tjønna et al. 2013 (2) [73]	0.942	0.413	0.132	1.752	0.023
	Wallman et al. 2009 [74]	-0.663	0.549	-1.739	0.413	0.227
	Zhang et al. 2017 (1) [76]	-0.750	0.378	-1.490	-0.010	0.047
	Zhang et al. 2017 (2) [76]	-0.762	0.378	-1.503	-0.021	0.044
	Subtotal	-0.192	0.072	-0.333	-0.050	0.008

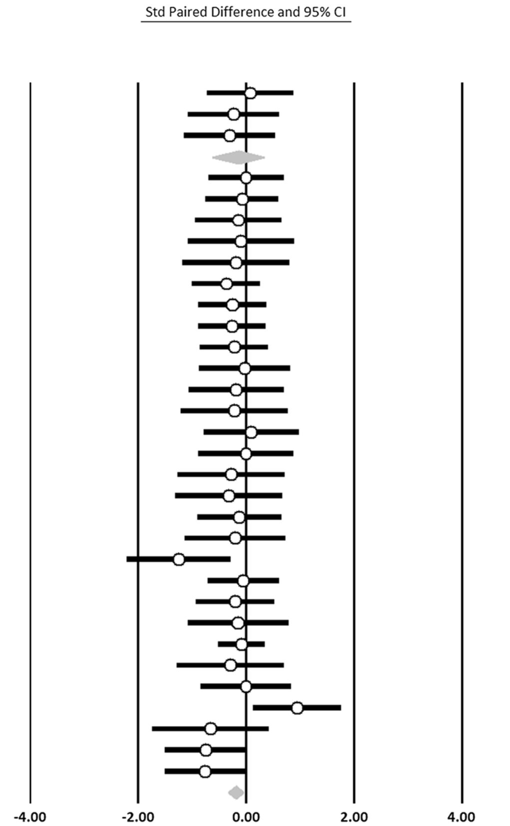


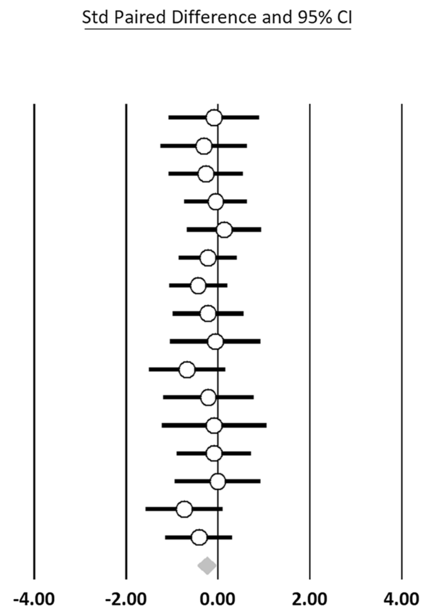
Fig. 3 continued

catecholamine responses significantly increase [35], which favors lipolysis via β-adrenergic receptors. The total abdominal area includes subcutaneous plus visceral adipose tissue. As the content of β-adrenergic receptors is higher in visceral than in subcutaneous adipose tissue [36], greater activation of the sympathetic nervous system (by noradrenaline release) during HIIT running could explain why there is a higher reliance on visceral adipose tissue than with a cycling protocol. However, little is known about the differences in catecholamine production during cycling and running performed at the same relative intensity, especially in overweight/obese subjects. Davies et al. [37] reported that catecholamine secretion was proportional to the muscle mass involved during exercise, a result at variance with the study of Nieman et al. [38], who observed no differences in catecholamine production between these two modalities. It is likely that the patients' habits (whether they go cycling and/or running, or even walking, regularly or not) could interfere with the results, as indicated by the great heterogeneity of our meta-analysis results regarding HIIT running-induced abdominal fat-mass loss. To conclude on this point, while our statistical analysis of 35 studies indicates that running is more effective than cycling in reducing whole-body fat mass (in part owing to the greater muscle mass involved and the higher post-exercise oxygen consumption), the choice of 'the best' modality to achieve higher abdominal and/or visceral fat-mass loss remains to be elucidated and could be patient-dependent if related to catecholamine responses. The lack of information regarding cycling programs, such as cycle ergometer used, revolutions per minute, resistance, watts, and heart rate, and running protocols, such as speed, gradient treadmill, and heart rate, sometimes make it difficult to compare the two modalities or studies using the same modality. Future studies with fuller details of the method used are needed to establish the best HIIT protocol to achieve total and abdominal/visceral fat-mass loss.

Three other parameters were taken into account in this meta-analysis. The first was the potential influence of sex difference. No sex-related effect was found for HIIT-induced reduction in total and abdominal or visceral fat mass. A meta-analysis of Vissers et al. [39] showed that physical activity (resistance or endurance training) in general had a greater impact on total and visceral fat mass in males than

(a)

Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Almenning et al. 2015 [47]	-0.085	0.500	-1.065	0.896	0.866
Arad et al. 2015 [48]	-0.307	0.474	-1.236	0.623	0.518
Cassidy et al. 2016 [49]	-0.263	0.410	-1.066	0.541	0.522
Fex et al. 2014 [24]	-0.046	0.343	-0.719	0.626	0.893
Hallsworth et al. 2015 [55]	0.140	0.409	-0.661	0.941	0.732
Heydari et al. 2012 (1) [56]	-0.214	0.317	-0.835	0.408	0.501
Heydari et al. 2012 (2) [56]	-0.426	0.320	-1.052	0.201	0.183
Hutchison et al. 2011 (1) [23]	-0.212	0.393	-0.982	0.559	0.591
Hutchison et al. 2011 (2) [23]	-0.050	0.500	-1.030	0.930	0.920
Karstoft et al. 2013 [59]	-0.665	0.419	-1.487	0.157	0.113
Maillard et al. 2016 [16]	-0.205	0.501	-1.187	0.778	0.683
Sandstad et al. 2014 [66]	-0.077	0.578	-1.209	1.055	0.894
Sasaki et al. 2014 [67]	-0.081	0.408	-0.881	0.720	0.843
Sawyer et al. 2016 [25]	0.000	0.471	-0.924	0.924	1.000
Zhang et al. 2015 [75]	-0.734	0.422	-1.561	0.092	0.082
Zhang et al. 2017 [76]	-0.412	0.369	-1.135	0.311	0.264
Total	-0.243	0.102	-0.444	-0.042	0.018



(b)

Group by Modality	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Cycling	Arad et al. 2015 [48]	-0.307	0.474	-1.236	0.623	0.518
	Cassidy et al. 2016 [49]	-0.263	0.410	-1.066	0.541	0.522
	Hallsworth et al. 2015 [55]	0.140	0.409	-0.661	0.941	0.732
	Heydari et al. 2012 (1) [56]	-0.214	0.317	-0.835	0.408	0.501
	Heydari et al. 2012 (2) [56]	-0.426	0.320	-1.052	0.201	0.183
	Maillard et al. 2016 [16]	-0.205	0.501	-1.187	0.778	0.683
	Sandstad et al. 2014 [66]	-0.077	0.578	-1.209	1.055	0.894
	Sasaki et al. 2014 [67]	-0.081	0.408	-0.881	0.720	0.843
	Sawyer et al. 2016 [25]	0.000	0.471	-0.924	0.924	1.000
	Zhang et al. 2017 [76]	-0.412	0.369	-1.135	0.311	0.264
	Subtotal	-0.212	0.128	-0.463	0.039	0.098
Elliptical	Fex et al. 2014 [24]	-0.046	0.343	-0.719	0.626	0.893
	Subtotal	-0.046	0.343	-0.719	0.626	0.893
	Hutchison et al. 2011 (1) [23]	-0.212	0.393	-0.982	0.559	0.591
	Hutchison et al. 2011 (2) [23]	-0.050	0.500	-1.030	0.930	0.920
	Karstoft et al. 2013 [59]	-0.665	0.419	-1.487	0.157	0.113
	Zhang et al. 2015 [75]	-0.734	0.422	-1.561	0.092	0.082
	Subtotal	-0.435	0.214	-0.855	-0.015	0.042
Running or cycling	Almenning et al. 2015 [47]	-0.085	0.500	-1.065	0.896	0.866
	Subtotal	-0.085	0.500	-1.065	0.896	0.866

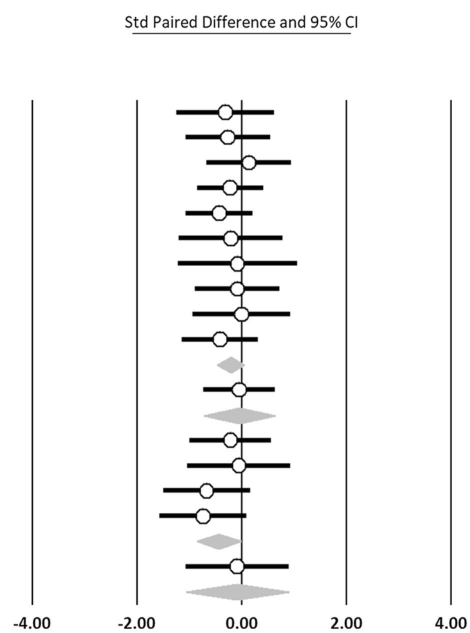
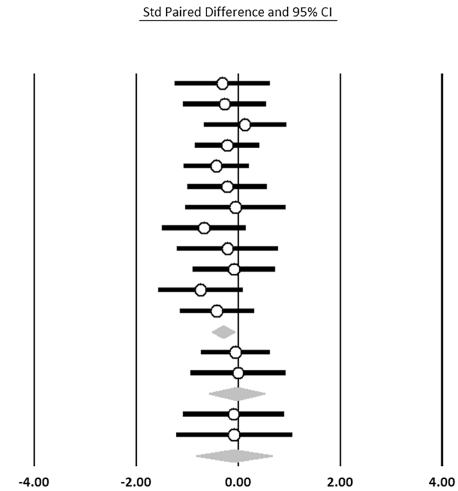


Fig. 4 Forest plot for the HIIT effect on (**a**) visceral fat mass, (**b**) with stratified analysis of exercise modalities, (**c**) methods of measuring body composition, (**d**) intensities, and (**e**) body weight. 1 and 2 represent the same study but different HIIT protocols. *CI* confidence interval, *CT* computed tomography, *DXA* dual-energy X-ray absorptiometry, *HIIT* high-intensity interval training, *MRI* magnetic resonance imaging, *NR* not reported, *Std* standardized

females according to their obesity phenotype: abdominal obesity in men and gynoid obesity in females, at least before menopause. However, only one study is available regarding sex differences in HIIT-induced fat-mass loss. The authors found a sex-related effect with a greater effect observed in males, but body composition was determined by impedance, which is not the most reliable method [40]. Thus, additional studies are still necessary, particularly comparisons of pre- and postmenopausal women, to draw any meaningful conclusions.

(c)

Group by: Methods of measuring body composition	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
CT-scan or MRI	Arad et al. 2015 [48]	-0.307	0.474	-1.236	0.623	0.518
	Cassidy et al. 2016 [49]	-0.263	0.410	-1.066	0.541	0.522
	Hallsworth et al. 2015 [55]	0.140	0.409	-0.661	0.941	0.732
	Heydari et al. 2012 (1) [56]	-0.214	0.317	-0.835	0.408	0.501
	Heydari et al. 2012 (2) [56]	-0.426	0.320	-1.052	0.201	0.183
	Hutchison et al. 2011 (1) [23]	-0.212	0.393	-0.982	0.559	0.591
	Hutchison et al. 2011 (2) [23]	-0.050	0.500	-1.030	0.930	0.920
	Karstoft et al. 2013 [59]	-0.665	0.419	-1.487	0.157	0.113
	Maillard et al. 2016 [16]	-0.205	0.501	-1.187	0.778	0.683
	Sasaki et al. 2014 [67]	-0.081	0.408	-0.881	0.720	0.843
	Zhang et al. 2015 [75]	-0.734	0.422	-1.561	0.092	0.082
	Zhang et al. 2017 [76]	-0.412	0.369	-1.135	0.311	0.264
	Subtotal	-0.295	0.115	-0.521	-0.069	0.011
DXA	Fex et al. 2014 [24]	-0.046	0.343	-0.719	0.626	0.893
	Sawyer et al. 2016 [25]	0.000	0.471	-0.924	0.924	1.000
	Subtotal	-0.030	0.277	-0.574	0.513	0.913
Other	Almenning et al. 2015 [47]	-0.085	0.500	-1.065	0.896	0.866
	Sandstad et al. 2014 [66]	-0.077	0.578	-1.209	1.055	0.894
	Subtotal	-0.081	0.378	-0.822	0.660	0.830



(d)

Group by: Intensity	Study name	Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
High	Almenning et al. 2015 [47]	-0.085	0.500	-1.065	0.896	0.866
	Hallsworth et al. 2015 [55]	0.140	0.409	-0.661	0.941	0.732
	Hutchison et al. 2011 (1) [23]	-0.212	0.393	-0.982	0.559	0.591
	Hutchison et al. 2011 (2) [23]	-0.050	0.500	-1.030	0.930	0.920
	Sawyer et al. 2016 [25]	0.000	0.471	-0.924	0.924	1.000
	Zhang et al. 2017 [76]	-0.412	0.369	-1.135	0.311	0.264
	Subtotal	-0.127	0.176	-0.472	0.218	0.471
Low	Arad et al. 2015 [48]	-0.307	0.474	-1.236	0.623	0.518
	Fex et al. 2014 [24]	-0.046	0.343	-0.719	0.626	0.893
	Heydari et al. 2012 (1) [56]	-0.214	0.317	-0.835	0.408	0.501
	Heydari et al. 2012 (2) [56]	-0.426	0.320	-1.052	0.201	0.183
	Karstoft et al. 2013 [59]	-0.665	0.419	-1.487	0.157	0.113
	Maillard et al. 2016 [16]	-0.205	0.501	-1.187	0.778	0.683
	Sandstad et al. 2014 [66]	-0.077	0.578	-1.209	1.055	0.894
	Sasaki et al. 2014 [67]	-0.081	0.408	-0.881	0.720	0.843
	Zhang et al. 2015 [75]	-0.734	0.422	-1.561	0.092	0.082
	Subtotal	-0.307	0.133	-0.567	-0.047	0.021
NR	Cassidy et al. 2016 [49]	-0.263	0.410	-1.066	0.541	0.522
	Subtotal	-0.263	0.410	-1.066	0.541	0.522

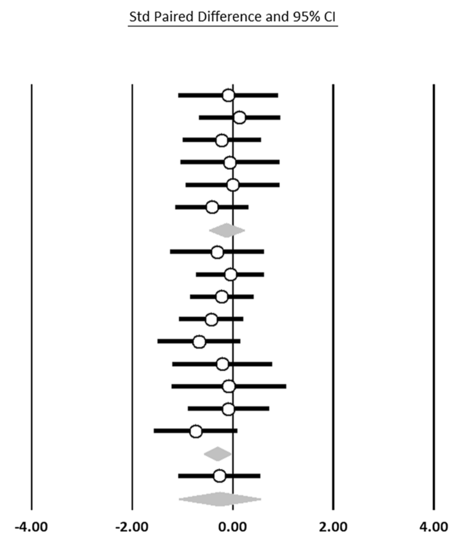


Fig. 4 continued

The second parameter was the method used to assess abdominal and visceral fat mass. Our analysis showed that only CT scan or MRI showed significant abdominal and/or visceral fat-mass changes after HIIT interventions. DXA scan is a 'gold-standard' instrument for measuring total fat mass, but, as shown by Shuster et al. [41], it is probably not the best method for assessing abdominal and, more particularly, visceral fat mass. Harmonizing the methods for measuring abdominal and visceral fat mass would help in the future to determine the real impact of HIIT on 'central obesity'.

The last parameter related to the intensity of the HIIT protocol. An HIIT program comprises eight main components: peak workload intensity, peak workload duration, recovery load, recovery duration, number of repetitions and series, and duration and intensity phases between series [42]. Endless combinations are possible and the isolated manipulation of each variable might differently affect the acute or chronic physiological responses [43]. Nevertheless, we arbitrarily chose to separate high and lower intensities using the threshold of 90% PHR. With this criterion, our meta-analysis showed that intensities above 90% PHR are more effective than lower intensities in reducing whole-body adiposity. In contrast, intensities below 90% PHR are more likely to decrease abdominal and visceral fat mass. In women aged 18–34 years, only a high

(e)

Group by	Study name	Statistics for each study				
Body weight		Std Paired Difference	Standard error	Lower limit	Upper limit	p-Value
Normal weight	Sandstad et al. 2014 [66]	-0.077	0.578	-1.209	1.055	0.894
	Sasaki et al. 2014 [67]	-0.081	0.408	-0.881	0.720	0.843
	Subtotal	-0.079	0.333	-0.733	0.574	0.812
Overweight-Obese	Almenning et al. 2015 [47]	-0.085	0.500	-1.065	0.896	0.866
	Arad et al. 2015 [48]	-0.307	0.474	-1.236	0.623	0.518
	Cassidy et al. 2016 [49]	-0.263	0.410	-1.066	0.541	0.522
	Fex et al. 2014 [24]	-0.046	0.343	-0.719	0.626	0.893
	Hallsworth et al. 2015 [55]	0.140	0.409	-0.661	0.941	0.732
	Heydari et al. 2012 (1) [56]	-0.214	0.317	-0.835	0.408	0.501
	Heydari et al. 2012 (2) [56]	-0.426	0.320	-1.052	0.201	0.183
	Hutchison et al. 2011 (1) [23]	-0.212	0.393	-0.982	0.559	0.591
	Hutchison et al. 2011 (2) [23]	-0.050	0.500	-1.030	0.930	0.920
	Karstoft et al. 2013 [59]	-0.665	0.419	-1.487	0.157	0.113
	Maillard et al. 2016 [16]	-0.205	0.501	-1.187	0.778	0.683
	Sawyer et al. 2016 [25]	0.000	0.471	-0.924	0.924	1.000
	Zhang et al. 2015 [75]	-0.734	0.422	-1.561	0.092	0.082
	Zhang et al. 2017 [76]	-0.412	0.369	-1.135	0.311	0.264
	Subtotal	-0.260	0.108	-0.471	-0.049	0.016

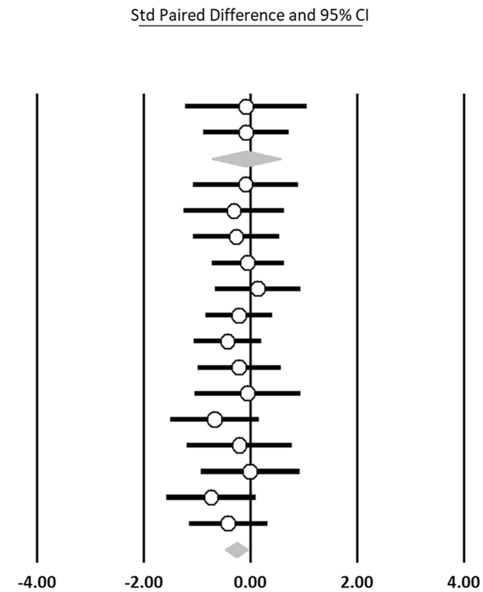


Fig. 4 continued

intensity (defined as heart rate around 160 and 165) has been shown to decrease total fat mass, and no effect was observed with lower intensities (heart rate around 150 and 160) [44]. The same result was found in untrained, middle-aged Korean females performing high- ($\geq 70\%\ \dot{V}O_2$max) or low-intensity (50% $\dot{V}O_2$max) exercises over 14 weeks [45]. With regard to abdominal and visceral fat mass, results in our study might appear surprising. The meta-analysis of Vissers et al. [39] on the effect of exercise on visceral fat mass in overweight adults suggested an intensity threshold and advised moderate (45–55% $\dot{V}O_2$max) to vigorous ($\geq 70\%\ \dot{V}O_2$max) exercise intensity to significantly decrease visceral fat mass [39]. In our meta-analysis, no moderate-intensity training was taken into account (i.e. low- to moderate-intensity interval training), and the lower intensities were still between 80 and 90% PHR owing to the threshold chosen. This may partly explain the results observed for abdominal/visceral fat mass since the duration of HIIT was generally longer when the intensity was lower. At these intensities, catecholamine release is still high and promotes lipolysis during exercise and fat oxidation during the recovery period.

5 Conclusions

Variations in the intensity and duration of the active and recovery periods, number of repetitions and series of the HIIT protocols combined with the lack of details regarding the cycling or running HIIT protocol itself make it difficult to analyze HIIT-induced fat-mass loss. Nevertheless, the results obtained with a wide range of HIIT protocols involving normal-weight and overweight/obese subjects suggest that HIIT, especially running, is a time-efficient strategy to decrease fat-mass deposits, including abdominal and visceral fat mass. Large, multicenter, prospective studies are required to establish the optimal HIIT protocols to reduce fat mass according to subject characteristics, such as age, sex, body adiposity, and metabolic disorders.

Compliance with Ethical Standards

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Conflict of interest Florie Maillard, Bruno Pereira and Nathalie Boisseau declare that they have no conflicts of interest relevant to the content of this review.

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