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Acute effect of high-intensity interval training versus moderate-intensity continuous training on appetite perception: A systematic review and meta-analysis

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ABSTRACT

Interval training protocols have gained popularity over the years, but their impact on appetite sensation compared to officially recommended training method, moderate intensity continuous training (MICT) is not well understood. Thus, this systematic review and meta-analysis aimed to compare a single session of high intensity interval training (HIIT) including sprint interval training (SIT) with MICT on appetite perception measured by the visual analog scale (VAS). After searching up articles published up to September 2021, 13 randomized controlled studies were included in the meta-analysis. Outcomes of meta-analysis demonstrated that both acute sessions of HIIT/SIT and MICT suppressed appetite compared to no-exercise control groups immediately post exercise but there were no significant effects 30–90 min post exercise or in AUC values, indicating a transient effect of exercise on appetite sensations. Moreover, differences in appetite sensations between HIIT/SIT and MICT were negligible immediately post exercise, but HIIT/SIT suppressed hunger (MD = −6.347 [-12.054, −0.639], $p = 0.029$) to a greater extent than MICT 30- to 90-min post exercise, while there was a lack of consistency other VAS subscales of appetite. More studies that address the impact of exercising timing, nutrient compositions of energy intake (energy intake (EI)) and differences in participants' characteristics and long-term studies analyzing chronic effects are needed to comprehensively examine the differences between HIIT/SIT and MICT on appetite and EI.

Systematic Review Registration: [https://www.crd.york.ac.uk/PROSPERO], Identifier [CRD42021284898].

1. Introduction

Exercise is a well-known strategy to promote improvements in overall health and facilitate weight management, yet the effect of exercise on weight reduction seems to be less prominent (Dorling et al., 2018; King, Hopkins, Caudwell, Stubbs, & Blundell, 2008). Acute exercise could induce energy deficits by increasing energy expenditure, while it may also generate a compensatory increase of energy intake (EI) induced by additional energy demand, which may partially account for the less than desired effect of exercise on weight reduction (Jakicic et al., 2001; King et al., 2012). A growing body of research has addressed the effects of exercise on appetite, an essential modifier of EI. Acute exercise stimuli have been reported to alternate appetite regulating hormones in a direction that suppresses subjective appetite (Schubert, Sabapathy, Leveritt, & Desbrow, 2014). Nevertheless, previous findings from individual studies are inconsistent regarding changes of subjective appetite after exercise (Dorling et al., 2018; Howe, Hand, & Manore, 2014). An important factor to explain the inconsistency is the differences in exercise intensity. Physiological responses to high intensity exercise (VO_{2max}>70%), such as blood redistribution, insulin concentration, and muscle metabolism that potentially influence appetite hormone signals (Hazell, Islam, Townsend, Schmale, & Copeland, 2016), could be different from the responses to lower intensity exercise, which may explain the greater suppression of hunger and stimulation of fullness (i.e., exercise-induced anorexia) observed in higher intensity exercise (Hazell et al., 2016; Pomerleau, Imbeault, Parker, & Doucet, 2004; Thivel et al., 2020). However, it must be noted that suppression in appetite perceptions is not necessarily translated into actual changes in

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EI given other variables (e.g. environmental conditions) contributing to the complex mechanism of human feeding behavior (King et al., 1997, 2012; Schubert, Desbrow, Sabapathy, & Leveritt, 2013).

High-intensity interval training (HIIT), which is characterized by short intermittent intervals with submaximal efforts (≥80% of maximal heart rate) interspersed with recovery periods, has been advocated as a more time-efficient way of improving health and fitness compared to moderate-intensity continuous training (MICT) (Keating, Johnson, Mielke, & Coombes, 2017; Martland, Mondelli, Gaughran, & Stubbs, 2020; Milanović, Sporiš, & Weston, 2015), while claims on the superiority of HIIT in the magnitude of clinical benefits and supplanting MICT with HIIT should be viewed cautiously (Ekkekakis & Biddle, 2022; Ekkekakis & Tiller, 2022). As a popular variation of HIIT, sprint interval training (SIT) involving shorter work intervals with all-out efforts may allow greater time efficiency compared to HIIT. Although there is evidence showing similar benefits of HIIT/SIT compared to MICT on weight reduction (Andreato, Esteves, Coimbra, Moraes, & De Carvalho, 2019; Bellicha et al., 2021; Wewege, Van Den Berg, Ward, & Keech, 2017), the mechanisms underlying the equivalent effects of HIIT/SIT compared to MICT are less clear. Thus, exploring appetite that potentially impacts energy intake and ultimately the efficacy of weight loss is crucial in understanding the potential mechanisms of the effects of HIIT/SIT on weight management. Given that exercise-induced changes of appetite could be intensity-dependent, it is reasonable to assume that HIIT or SIT with higher intensity may also provide more favorable outcomes for appetite regulation than MICT with lower intensity. However, current evidence from randomized control studies is not consistent regarding the effects of HIIT/SIT on appetite compared to MICT. Some studies supported HIIT/SIT in suppressing hunger and lowering appetite to a greater extent than MICT (Deighton, Barry, Connon, & Stensel, 2013; Deighton, Karra, Batterham, & Stensel, 2013; Hallworth, Copeland, Doan, & Hazell, 2017), while others suggested no differences between MICT and HIIT/SIT on the changes of appetite (Martins et al., 2015; Sim, Wallman, Fairchild, & Guelfi, 2014). A recent systematic review and meta-analysis (Beaulieu et al., 2021) have investigated the effects of structured exercise training programs on appetite in overweight or obese adults, and small to negligible changes in appetite were found. Despite attempting to examine appetite responses to different training modalities through sub-group analysis, the aforementioned meta-analysis did not perform direct comparisons between HIIT and MICT due to the small number of available studies. Therefore, it remains unclear whether the acute effects of HIIT and SIT on appetite would be different from that of MICT.

To examine the impact of different training modalities (i.e., HIIT, SIT, and MICT) with varied intensity, this review aimed to synthesize current results from available studies to compare acute effects of HIIT and SIT with MICT on appetite sensations (i.e., hunger, fullness, desire to eat, prospective food assumption, satisfaction) in healthy individuals with either normal or excess weight.

2. Method

2.1. Search strategy

The literature search was conducted using the following databases: PubMed, Web of Science and ScienceDirect, Scopus, and Cochrane Library to find possible eligible studies that have undergone peer-review and published in English until September 1, 2021. Combinations of keywords were applied to "all fields", "title" and "abstract" as follows: "exercise" OR "physical activity" OR "high intensity training" AND "appetite" OR "hunger" OR "satiation" OR "satiety" OR "fullness" OR "desire to eat" OR "motivation to eat" OR "visual analogue scale" OR "feeding behavior" OR "energy intake" OR "food intake". The PRISMA guideline (Preferred Reporting in Systematic Reviews and Meta-Analyses) was followed throughout the preparation of the current study which has been registered in the PROSPERO database (registration number CRD42021265959).

2.2. Study selection

Selected studies were required to meet the following inclusion criteria: 1) published in English and implemented randomized study design involving parallel groups or cross-over design; 2) participants were healthy active or inactive adults with either normal or excess weight (i.e., including overweight to obsess subjects without medical conditions); 3) involved HIIT or SIT exercise interventions with either one (i.e., acute) or multiple exercise sessions and MICT acted as the comparator. 4) compared effects (i.e., acute or short- to long-term effects) of HIIT or SIT with MICT on outcomes of subjective appetite (i.e., hunger, fullness, desire to eat, prospective food assumption). Although the search included long-term studies, only two 12-week studies have been identified after the screening. Therefore, the present study only focused on acute appetite responses to a single HIIT/SIT or MICT session. HIIT is defined as exercise protocols with alternation of short high-intensity work bouts (≤4-min each bout) with near the maximal or supramaximal efforts (≥80% of the maximum heart rate (HR_{max}) or ≥85% maximal oxygen consumption (VO_{2max}) and recovery periods, while SIT is defined as exercise protocols with short "all-out" training bouts (≤30 s each bout) interspersed with recovery periods (Buchheit & Laursen, 2013). MICT is defined as protocols involving exercise performed continuously at a moderate intensity (45–65% HR_{max} or 45–65% VO_{2max}) for 20–60 min in this review (Riebe et al., 2015). There were no restrictions for exercise mode applied as long as the compared groups were performed in the same exercise mode (e.g., running, cycling). Studies would be excluded if only analyzed one training protocol (i.e., exercise protocol versus non-exercise control group), and if not measured subjective appetite.

All studies were recorded using electronic forms after searching. Replicated studies were removed before the title and abstract screening started. Excluded studies were labeled by reasons of exclusion. Full texts were screened to make the final decision of inclusion when studies were eligible after the title and abstract screening.

2.3. Data extraction and synthesis

The extracted data from the final eligible studies included the name of the first author and study publication year, participants (i.e., sample size, gender, body mass index (BMI), fitness level), study design (i.e., between-subject or within-subject), characteristics of the exercise protocols (i.e., length, intensity, energy expenditure if available), information about provided test meals (type of foods, macronutrients, energy provided), outcome data for appetite sensations (i.e. hunger, fullness, satisfaction, perspective food assumption, desire to eat specific foods) measured through the visual analogue scale (VAS) in or converted to millimeter (mm) (Flint, Raben, Blundell, & Astrup, 2000). The VAS is a scale using a 100-mm straight line with two anchored responses at either end to answer a simple question by choosing any point on the line. An example question would be "how hungry are you?" and the responses would be "I am not hungry at all" and "I have never been hungrier" at the two ends. Studies published in the same year by the same first author were labeled with an asterisk, e.g., Deighton, Barry, et al. (2013) * for the latter published one. All outcomes extracted were presented as or converted to means and standard deviations in each experimental group (i.e. HIIT or SIT and MICT). The authors were contacted to request raw data if outcomes were not reported in their studies.

2.4. Risk of bias

The Cochrane Risk of Bias tool (Higgins et al., 2011) was used to assess the risk of bias in the included studies, which consists of domains accessing selection bias in the randomization process, attrition bias due to missing outcome data, and reporting bias due to selective reporting.

The risk of bias for blinding was not assessed, as the study design all involved exercise interventions which could not be concealed from the participants or the personnel. For cross-over trials, the risk of bias arising from period and carryover effects was accessed using the Revised Cochrane risk-of-bias tool for randomized crossover trials.

2.5. Analysis

Acute effects of exercise (i.e., HIIT/SIT and MICT) versus the control group (CON) and HIIT versus MICT on appetite sensations (i.e., hunger, fullness, satiety or satisfaction and prospective food consumption (PFC) measured by the VAS and absolute and/or relative energy intake (EI) at ad libitum test meals were analyzed using random effects meta-analysis performed in Comprehensive Meta-Analysis software (version 3, New Jersey, USA).

We compared subjective appetite responses to exercise protocols (i.e. HIIT/SIT and MICT) and CON, HIIT/SIT and MICT immediately post exercise and 30-min to 90-min post exercise and the area under curve (AUC) appetite ratings before lunch on an experimental day. The time points chosen were based on the fact that the majority of studies incorporated half-day experiments, which typically provided breakfast upon arrival and 1 h rest before exercise, and then allowing 30- to 90-min rest after exercise before the ad libitum test meal, and subjective appetite ratings were measured three times post exercise: 1) immediately post exercise, 2) in the middle of the recovery period (30–50 min or $<$ 1 h post exercise) and 3) right before lunch (60–90 min or $>$ 1 h post exercise). AUC values were calculated using the trapezoidal method with available raw data provided by the authors of the included studies (Deighton, Barry, et al., 2013; Hallworth et al., 2017; Hazell, Islam, Hallworth, & Copeland, 2017; Islam et al., 2017; Martins et al., 2015; Panissa et al., 2019).

Data from studies that included more than one HIIT protocol or reported post exercise appetite sensations at different time points (e.g. 30-min post and 60-min post before lunch) were separated as studies arms with halved sample size in each arm to reduce the likelihood of over-weighting. Analysis of differences in means (MD) was performed for all outcomes except for analyses of AUC values which were performed in standard mean difference (SMD), given the variations in measurement time and time interval. To identify any differences in appetite responses and EI to HIIT and SIT compared with MICT, outcomes from the analyzed studies were divided into subgroups by protocol types (i.e., SIT or HIIT) to compare the effect of HIIT and SIT relative to MICT. Effect sizes are interpreted as trivial if SMD $<$0.2, as small if 0.2–0.3, as moderate if 0.5, and as large if $>$ 0.8 (Cohen, 1992). Despite that all studies included in the meta-analysis were cross-over trials, carry-over effects were considered negligible as a sufficient wash-over period was provided in every included study with such a design. Because no differences were found after performing sensitivity analysis using standard paired differences and correlation coefficients of 0.6, 0.7, 0.8, and 0.9, a default correlation coefficient of 0.5 was used to conduct the meta-analysis. Visual inspection of the funnel plot and Egger's regression test was performed to assess publication bias when study arms were more than 10. Heterogeneity was interpreted as low ($<$25%), moderate (25%–75%), and high ($>$75%) using values of I-squared statistic (I^2) (Patsopoulos, Evangelou, & Ioannidis, 2008). When levels of heterogeneity are high ($>$75%) in the meta-analysis, sensitivity analysis would be performed first to identify if one or more input data sets contribute to the heterogeneity level. For analyses with more than 10 study arms, protocol types, BMI, gender, and fitness level (active or inactive) of the participants, measurement time ($\leq$1 h or $>$ 1 h) for post exercise appetite sensation, and energy expenditure in HIIT or SIT and MICT (i.e., energy matched or not) would be used as moderators to perform sub-group analyses and restricted maximum likelihood random-effects meta-regression.

3. Results

A total of 13 studies were included in the current review after study selection. Data from 12 studies out of 13 studies were used in the meta-analysis. Data from one study analyzing sex differences were used in the narrative synthesis (Hazell, Townsend, Hallworth, Doan, & Copeland, 2017). Procedures of selection and reasons for exclusion were presented in the flow diagram (Fig. 1). Summary of risk of bias evaluations of all included studies was presented in Supplementary Fig. S1.

3.1. Study characteristics

The characteristics of the included study are demonstrated in Table 1. The studies were published between 2012 and 2019, and more than half of studies were published in or after 2016 (n = 9). All the included studies (n = 13) used a cross-over design to compare the acute effects of HIIT and MICT on appetite In total, the 13 included studies (Deighton, Barry, et al., 2013; Deighton, Karra, et al., 2013; Hallworth et al., 2017; Hazell, Islam, et al., 2017; Hazell, Townsend, et al., 2017; Islam et al., 2017; Larsen et al., 2019; Martins et al., 2015; Matos et al., 2018; Panissa et al., 2016; Panissa et al., 2019; Poon, Sun, Chung, & Wong, 2018; Sim et al., 2014) involved 169 healthy adult individuals of both sexes, but most individuals were males (n = 133). Nearly half of the studies (n = 5) analyzed appetite responses from overweight subjects (Larsen et al., 2019; Martins et al., 2015; Matos et al., 2018; Panissa et al., 2019; Sim et al., 2014), while the other 8 studies involved normal weight individuals (Deighton, Barry, et al., 2013; Deighton, Karra, et al., 2013; Hallworth et al., 2017; Hazell, Islam, et al., 2017; Hazell, Townsend, et al., 2017; Islam et al., 2017; Panissa et al., 2016; Poon et al., 2018). Young (e.g., 22 ± 3 years old) to middle-aged (e.g., 45.7 ± 7.4 years old) individuals were recruited in the included studies.

Analyzed HIIT protocols (six studies) involved 30- to 240-s intervals at 85–100% VO_{2max} and SIT protocols (eight studies) with 8- to 30-s intervals eliciting all-out effort or $>$100% $VO_{2peak.}$ Two studies analyzed both HIIT and SIT in comparison to MICT (Panissa et al., 2016; Sim et al., 2014). Duration of MICT protocols at 60–65% VO_{2max} or 70–72%HR_{max} ranged from 20-min to 60-min, while the most common duration was 30-min, which was used in six studies. The majority of studies (n = 11) used cycling as an exercise mode, while two studies used treadmills (n = 2) (Islam et al., 2017; Matos et al., 2018). Five out of 15 studies compared energy-matched HIIT and MICT protocols (Deighton, Barry, et al., 2013; Larsen et al., 2019; Martins et al., 2015; Panissa et al., 2016; Sim et al., 2014), while four studies incorporated HIIT/SIT with lower energy expenditure than MICT (Deighton, Karra, et al., 2013; Hazell, Townsend, et al., 2017; Islam et al., 2017), and one study used HIIT with slightly higher energy expenditure than MICT (Panissa et al., 2019). Three studies did not provide information on the energy expenditure of the training protocols (Hallworth et al., 2017; Hazell, Islam, et al., 2017; Matos et al., 2018).

All studies except one (Larsen et al., 2019) provided standardized breakfast for participants, but the standards of the breakfast (i.e., types of food, energy, and macronutrients provided) used were not the same as presented in Table 1. Regarding the types of food in breakfast, five studies provided a continental breakfast (i.e., bread, jam, juice) without tea or coffee (Deighton, Barry, et al., 2013; Deighton, Karra, et al., 2013; Martins et al., 2015; Panissa et al., 2016; Panissa et al., 2019); four studies provided energy bars with or without rice cake and peanut butter (Hazell et al., 2016; Hazell, Islam, et al., 2017; Hazell, Townsend, et al., 2017; Islam et al., 2017); and three studies provided a liquid meal consisting of energy powder reconstituted in water (Matos et al., 2018; Poon et al., 2018; Sim et al., 2014). Total energy intakes during breakfast were different across studies: five studies used body weight to calculate the energy contained in breakfast (4 or 4.5 or 7 kcal/kg) (Hallworth et al., 2017; Hazell, Islam, et al., 2017; Hazell, Townsend, et al., 2017; Islam et al., 2017; Matos et al., 2018), three estimated energy needs for each individual and set 20%, or 25% or 30% energy needs

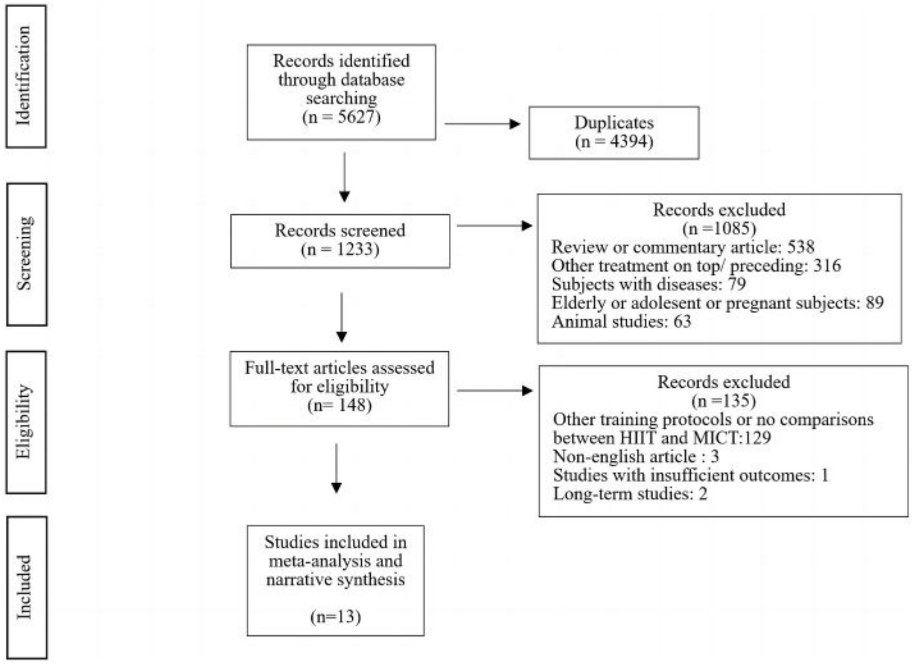

Fig. 1. Flow diagram of screening and selection of articles for review.

during breakfast and two studies provided breakfast with a fixed energy of 600 kcal (Martins et al., 2015) or 268 kcal (Sim et al., 2014). Macronutritional components of the breakfast reported by eight studies were varied across studies: breakfast was composed of 48%–87.5% of carbohydrates, 1.3%–36% of fats, and 9.5% to 17% of proteins in total energy intake.

3.2. Exercise versus no-exercise controls on appetite

Outcomes of exercise groups (i.e., EXE: HIIT/SIT and MICT) compared to no-exercise control groups (CON) on appetite immediately post exercise and 30-min to 90-min post exercise are presented in Fig. 2 (hunger), Fig. 3 (fullness), supplementary Figure S2 (PFC) and Fig. S3 (satisfaction). When compared to no-exercise control groups, both HIIT/SIT and MICT suppressed appetite immediately post exercise. Specifically, a meta-analysis demonstrated that exercise training resulted in significantly lower hunger perception (MD = - 8.465 [−13.095, - 3.834], $p < 0.001$) and PFC (MD = −15.863 [−22.969, −8.757], $p < 0.001$), higher fullness (MD = 5.636 [0.639, 10.634], $p = 0.027$) and satisfaction (MD = 13.986 [7.628, 20.343], $p < 0.001$) immediately post exercise. Nevertheless, there were no significant effects of exercise compared to the controls on hunger, PFC, and fullness 30- to 90-min post exercise ($p > 0.05$), despite a higher satisfaction presented in exercise groups (MD = 5.974 [0.889, 11.049], $p = 0.021$), indicating a transient effect of exercise on appetite suppression. Although subgroup analysis showed greater effect sizes of SIT compared to MICT on analyses of every subscale of appetite perceptions (i.e., hunger, PFC, fullness, and satisfaction) immediately and 30- to 90-min post exercise, significant effects of SIT compared to the CON only generated in PFC and satisfaction immediately post exercise, and hunger and satisfaction 30- to 90-min post exercise. Analyses for the AUC values were presented in Supplementary Fig. S4. No significant effects of the exercise groups compared to the CON were observed in any of the subscales of appetite ($p > 0.05$). Heterogeneity was low in the majority of the outcomes except for the analysis of hunger (I^2 = 32.03%) and PFC perception (I^2 = 35.17%) immediately post exercise.

3.3. HIIT/SIT versus MICT on appetite

Meta-analysis of 10 studies (17 study arms) examining the effect of HIIT or SIT compared to MICT on hunger perception is demonstrated in Fig. 4. Hunger perceptions were not significantly different immediately after HIIT or SIT compared to MICT ($p > 0.05$), and the effect was not significantly different across subgroups of HIIT ($p = 0.293$) and SIT ($p = 0.105$). Results of hunger perception 30 min–90 min post exercise showed a greater hunger in MICT compared to HIIT and SIT (MD = −6.347 [−12.054, −0.639], $p = 0.029$), and the effect size was small (SMD = −0.258). Differences were observed in between the subgroup of HIIT (6 arms) (MD = −2.475 [−10.441, −5.492], $p = 0.543$) and SIT (10 arms) (MD = −10.430 [−18.193, −2.249], $p = 0.012$), suggesting SIT might suppress hunger to a greater extent compared to MICT, while HIIT might elicit comparable effects as MICT in hunger perceptions. However, no significant differences in AUC values of hunger were found between MICT and HIIT/SIT ($p > 0.05$) (Fig. S5). Low to moderate heterogeneity (i.e., I^2 = 0% in the analysis of immediate post exercise hunger and AUC values and I^2 = 29.8% in post + outcomes) was detected in the analyses of post-exercise hunger perceptions, while some published bias was detected from visual inspection of the funnel plot. Egger's regression intercept was −5.35 ($p = 0.01$).

Outcomes from eight studies (13 study arms) that reported fullness perceptions were depicted in Fig. 5. No significant differences between HIIT or SIT and MICT were found immediately post exercise) nor 30–90 min post exercise ($p > 0.05$). No other significant effects in subgroups analysis of protocol types were observed in fullness perceptions. There were also no significant differences found in the AUC values of fullness ($p > 0.05$) as presented in Fig. S5. Heterogeneity was not found in the analysis of fullness immediately post exercise and in AUC values (I^2 = 0%) but was moderate in the analysis of fullness 30- to 90- min post exercise (I^2 = 27.6%). Funnel plot and Egger's test ($p = 0.08$) suggested some chance of publication bias and a small sample size of the analyzed studies.

Outcomes for the meta-analysis of prospective food consumption (PFC) from five studies (10 study arms) were presented in Fig. 6. Results suggested greater PFC in MICT immediately post exercise (MD = −11.581 [−19.229, −3.932], $p = 0.003$) with a moderate effect size (SMD: - 0.497), but no significant differences were observed between

Table 1
Study characteristics and outcomes of all included studies.

Study	Participants		Exercise training intervention		Pre-exercise meal	Outcomes (measurement time)
	N (gender)	BMI (kg/ m^2)	HIIT/SIT (energy deficits)	MICT (energy deficits)	Breakfast	Appetite sensation
Deighton, Barry, et al. (2013)	12(M)	23.7 ± 3	HIIT: 240 s cycling at 85–90% VO_{2max} +120 s rest (~580 kcal)	cycling at 60% VO_{2max} for 60-min (~585 kcal)	consisted of toasted white wheatgerm bread, margarine, strawberry jam, banana and orange juice (30% of estimated daily energy needs; 72.9% carbohydrate, 9.5% protein and 17.6% fat) -consumed within 15 min after arrival	Overall appetite (hunger, satisfaction, fullness, and prospective food consumption (PFC) measured at baseline, 0.25, 2 h and every 30 min thereafter)
Deighton, Barry, et al. (2013)*	12(M)	24.2 ± 2.9	SIT: 6 × 30 s sprinting against 7.5% of body mass+ 240 s passive recovery (~142 kcal)	cycling at 68.1 ± 4.3% VO_{2max} for 60-min (~630 kcal)	consisted of toasted white wheatgerm bread, margarine, strawberry jam, banana and orange juice (30% of estimated daily energy needs; 72.9% carbohydrate, 9.5% protein and 17.6% fat) -consumed within 15 min after arrival	Hunger, Fullness, Satisfaction, PFC (measured at baseline, 0.25, 1.75, 2.25, 2.5, 2.75, 3 h and every 30 min thereafter) – raw data acquired
Hallworth et al. (2017)	9(F)	23.5 ± 2.8	SIT: 6 × 30 s sprinting against 10% of body mass + 240 s passive recovery	cycling at 65% VO_{2max} for 30-min	consisted of an energy bar (1050 kJ), plain Quaker rice cake (147 kJ), and natural peanut butter (up to remaining allotted kJ: 16.7 $kJ{\cdot}kg^{-1}$) -consumed within 15 min	Hunger (measured before breakfast, before exercise, immediately after, and 90-min after exercise) – raw data acquired
Hazell, Townsend, et al. (2017)	21 (11F,10M)	23.7 ± 2.2	SIT: 6 × 30 s sprinting against 10% of body mass + 240 s passive recovery	cycling at 65% VO_{2max} for 30-min	consisted of an energy bar (1050 kJ), plain Quaker rice cake (147 kJ), and natural peanut butter (up to remaining allotted kJ: 16.8 $kJ{\cdot}kg^{-1}$) -consumed within 15 min after arrival	Hunger (measured before exercise, immediately after, and 90-min after exercise)
Hazell, Townsend, et al. (2017)*	10(M)	23.7 ± 2.2	SIT: 6 × 30 s sprinting against 10% of body mass + 240 s passive recovery (~142 kcal)	MICT: cycling at 65% VO_{2max} for 30-min (356.0 ± 22.3 kcal) HICT: cycling at 85% VO_{2max} for 30-min (456.5 ± 28.6 kcal)	consisted of an energy bar (1050 kJ), plain Quaker rice cake (147 kJ), and natural peanut butter (up to remaining allotted kJ: 16.8 $kJ{\cdot}kg^{-1}$) -consumed within 15 min after arrival	Hunger (measured before breakfast, before exercise, immediately after, and 90-min after exercise) – raw data acquired
Islam et al. (2017)	8(M)	24.8 ± 2.3	SIT: 4 × 30 s 'all-out' running + 4-min rest (132.3 ± 8.2 kcal)	MICT: running at 65% VO_{2max} for 30-min (396.1 ± 28.8 kcal) HICT: running at 85% VO_{2max} for 30-min (492.8 ± 33.4 kcal)	consisted of an appropriate amount (7 kcal/kg) chocolate chip energy bar (68% carbohydrates, 17% fat, 15% protein) -consumed within 15 min after arrival	Overall appetite (hunger, satisfaction, fullness PFC measured before exercise, immediately after, 30-min after and 90-min after exercise) – raw data acquired
Larsen et al. (2019)	11(M)	28 ± 3	HIIT: 60 s cycling at 100% VO_{2peak} +240s active recovery at 50% VO_{2peak}	cycling at 60% VO_{2max} for 30-min (work done matched with HIIT)	Not provided	Hunger Fullness (measured pre-, 30-min post- exercise and the morning at the second day of the exercise day) – raw data acquired
Martins et al. (2015)	12 (7F,5M)	32.3 ± 2.7	SIT: 8 s sprinting at 85–90% HR_{max}+ 12 s active recovery for 18 ± 3 min (250 kcal) SIT (half volume): same protocol as above for 9 ± 2 min (125 kcal)	cycling at 70% HR_{max} for 27 ± 6 min (250 kcal)	consisted of bread, orange juice, milk, cheese, and jam (600 kcal, 17% protein, 35% fat, and 48% carbohydrate) -consumed within 10 min after arrival	Hunger, Fullness Desire to eat (measured at baseline, after breakfast, pre-, during- post-exercise and every 30 min until lunch) – raw data acquired
Matos et al. (2018)	12 (M)	35.5 ± 4.5	HIIT: 10 × 60s running at 90% of maximal heart rate with 60s recovery	running at 70% of maximal heart rate for 20 min	a liquid meal consisted of powdery reconstituted in water (4.5 kcal/kg) (87.5% carbohydrates, 11.2% proteins, and 1.3% fat)	Hunger, Fullness, Satisfaction, PFC (measured before, immediately after and 60 min after exercise)
Panissa et al. (2016)	20 (9F,11M)	~23 (F) ~24.6 (M)	SIT: 60 × 8 s sprinting + 12 s passive recovery for 20-min (8 min of effort and 12 min of pause) (~192 ± 57 kcal) HIIT: 60 s cycling at 100% of maximal load attained in incremental test + 60 s passive recovery for 17 ± 2 min (9 min of effort and 8 min of pause) (~155 ± 55 kcal)	cycling at 60% of 100% of maximal load attained in incremental test for 19 ± 2 min (~161 ± 53 kcal)	consisted of cheese, toast, and strawberry yogurt (25% of the estimated daily energy needs: 52% carbohydrate, 36% fat, and 13% protein) - consumed ~2 h before exercise	Hunger (measured before, immediately after and 45-min and 90-min after exercise)
Panissa et al. (2019)	14(M)	29.3 ± 2.4	HIIT: 30 s cycling at maximal aerobic power (70 rpm) + 30 s passive recovery for 30-min (~288 ± 29 kcal)	cycling at 50% of maximal intensity attained for 30-min (~254 ± 27 kcal)	consisted of bread, butter, cereal and strawberry yogurt (20% of the estimated daily energy needs: 10–15% protein, 55–75% carbohydrate and 15–30% fat) -consumed within 15 min after arrival and 1 h vs. 2.5 h before exercise	Hunger, Fullness Desire to eat specific types of foods (sweet, fatty, salty and savory) (measured before, immediately after and 45-min and 90-min after exercise) – raw data acquired

(continued on next page)

Table 1 (*continued*)

Study	Participants		Exercise training intervention		Pre-exercise meal	Outcomes (measurement time)
	N (gender)	BMI (kg/ m²)	HIIT/SIT (energy deficits)	MICT (energy deficits)	Breakfast	Appetite sensation
Poon et al. (2018)	11(M)	23.5 ± 2.1	HIIT: 10 × 60s at 100% VO_{2max} with 60s active recovery at 50% VO_{2max} (216 ± 29 kcal)	MICT: cycling at 65% VO_{2max} for 40-min (365 ± 43 kcal) MVCT: cycling at 80% VO_{2max} for 20-min (222 ± 32 kcal)	consisted of wholegrain cereal and sport powder (a carbohydrate (CHO) dose of 1.5 g/kg body mass) - consumed 1 h before exercise	Overall appetite and sub-scores of hunger, satisfaction, fullness PFC (measured before, immediately after and 1h after exercise)
Sim et al. (2014)	17 (M)	27.7 ± 1.6	SIT: 15 s sprinting at 170% VO_{2peak} + 60 s active recovery for 30-min (~54 ± 10 kcal) HIIT: 60 s cycling at 100% VO_{2peak} + 240 s active recovery for 30-min (~55 ± 10 kcal)	cycling at 60% VO_{2peak} for 30-min (~54 ± 10 kcal)	a liquid meal (350 ml, 1120 kJ or 268 kcal; 61% carbohydrates, 15% protein and 30% fat) -consumed within 2 min after exercise	Hunger, Fullness, Satisfaction, Desire to eat, PFC (measured before, immediately after and 30-min, 60-min and 90-min after exercise)

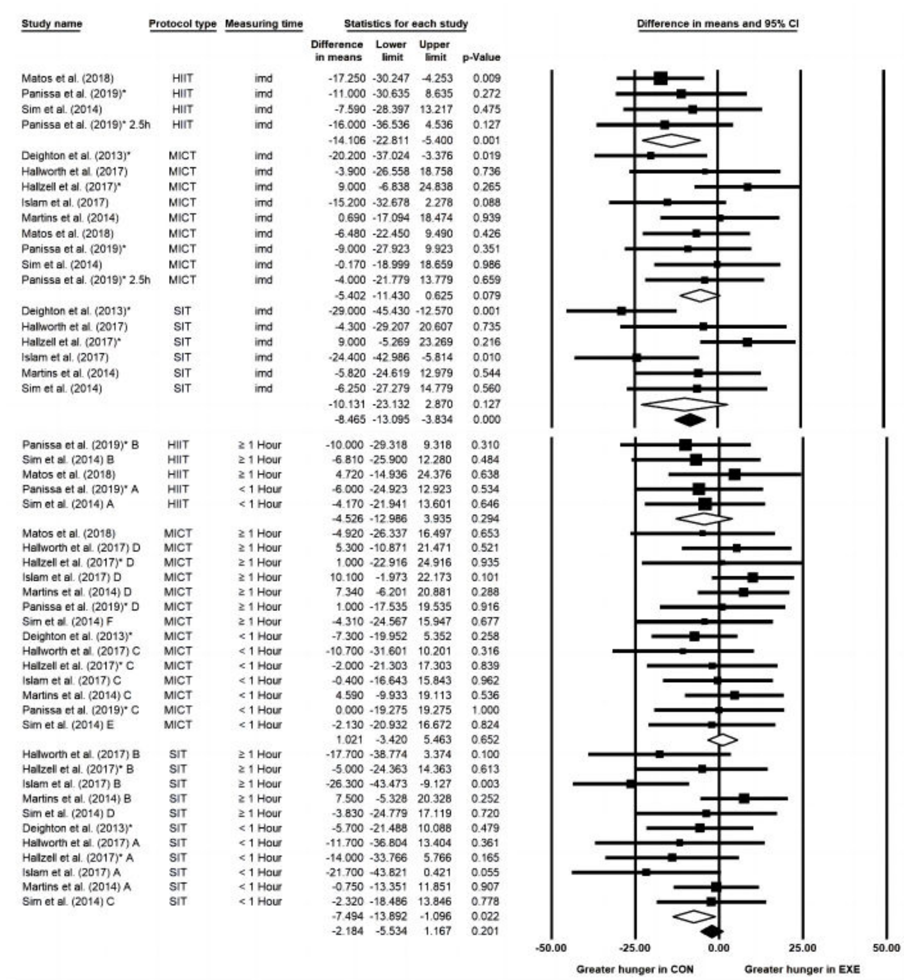

Fig. 2. Effects of exercise (EXE) vs. control (CON) on hunger perception immediately and 30–90 min post exercise.

HIIT or SIT and MICT 30–90 min post exercise nor in the AUC values ($p > 0.05$) (Fig. S5). Subgroup analysis of protocol types (2 arms in HIIT and 4 arms in SIT) suggested MICT induced significantly greater PFC compared with SIT immediately post exercise (MD = −14.581 [−24.329, −4.746], $p = 0.004$) and the effect size was moderate to large (SMD: - 0.755). Heterogeneity was moderate in the analysis of PFC immediately post exercise ($I^2 = 28.61\%$) and 30- to 90-min post exercise ($I^2 = 42.526\%$).

Five studies (eight study arms) reported satisfaction post exercise, and the results were presented in Fig. S6. Results showed no significant differences between HIIT/SIT and MICT immediately post exercise nor 30- to 90-min post exercise nor in AUC values (($p > 0.05$) (Fig. S5)). Subgroup analysis of protocol types (2 arms in HIIT and 3 arms in SIT) revealed greater effects of SIT compared to MICT on satisfaction immediately post exercise (MD = 13.765 [0.628, 26.902], $p = 0.04$). Heterogeneity was very low in the analysis of ratings of satisfaction immediately, 30- to 90-min post exercise, and AUC values ($I^2 = 0\%$).

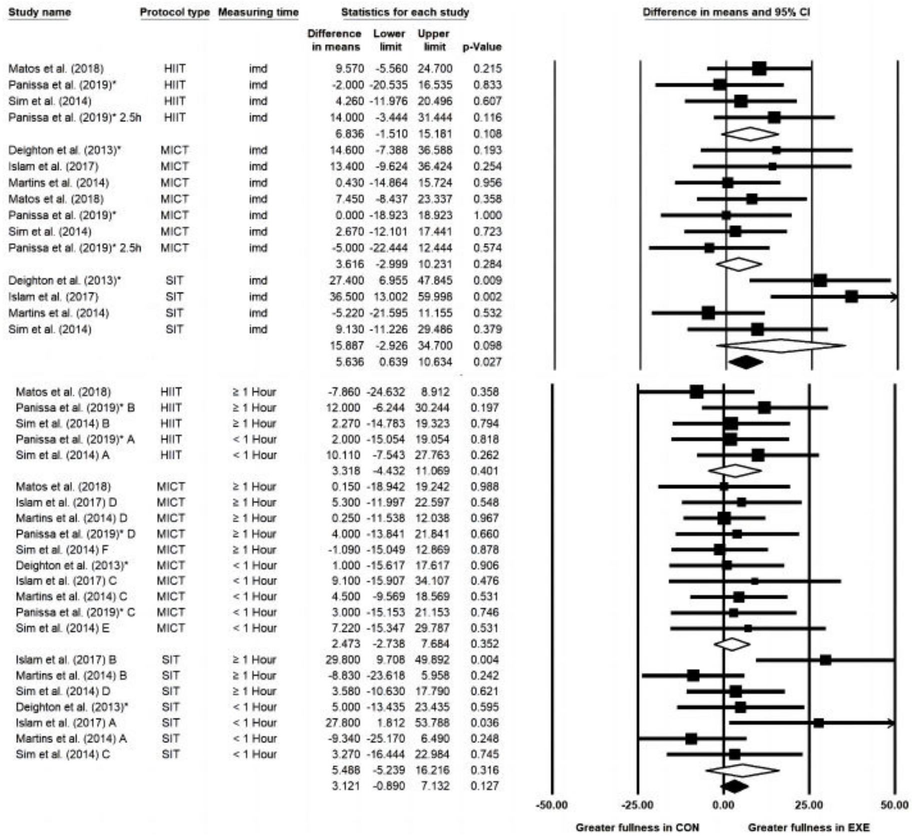

Fig. 3. Effects of exercise (EXE) vs. control (CON) on fullness perception immediately and 30–90 min post exercise.

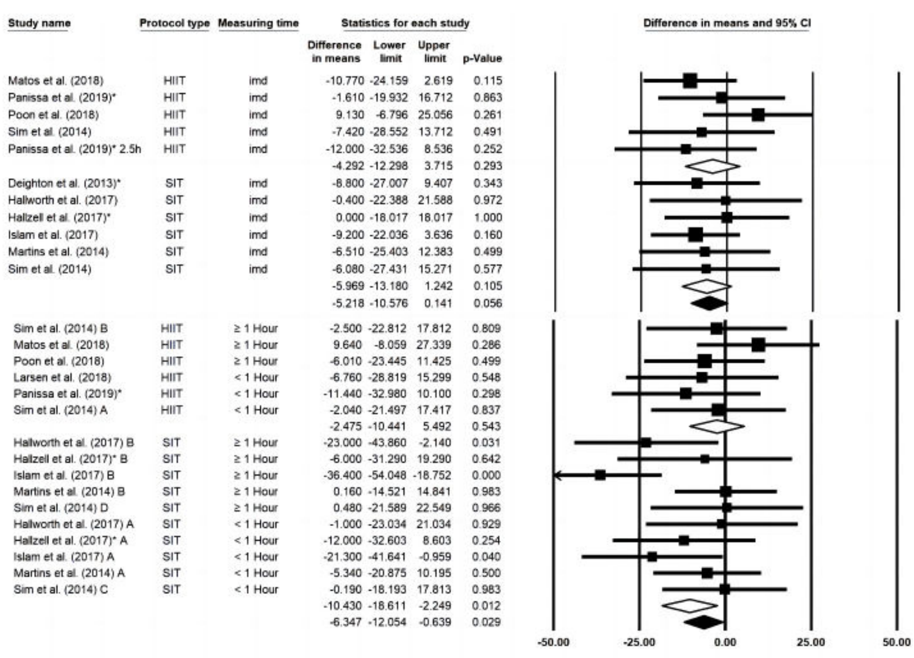

Fig. 4. Effects of HIIT/SIT vs. MICT on hunger perception immediately and 30–90 min post exercise.

4. Discussion

The current systematic review and meta-analysis compared acute appetite responses to HIIT and SIT with MICT. Meta-analyses demonstrated that both HIIT/SIT and MICT suppressed appetite compared with the no-exercise control groups immediately post exercise, but the effects did not last 30- to 90-min post exercise. When compared with MICT, HIIT/SIT suppressed hunger perception 30- to 90-min post exercise and PFC immediately post exercise to a greater extent, and larger effect sizes were generated in the subgroup of SIT. However, the results of the meta-

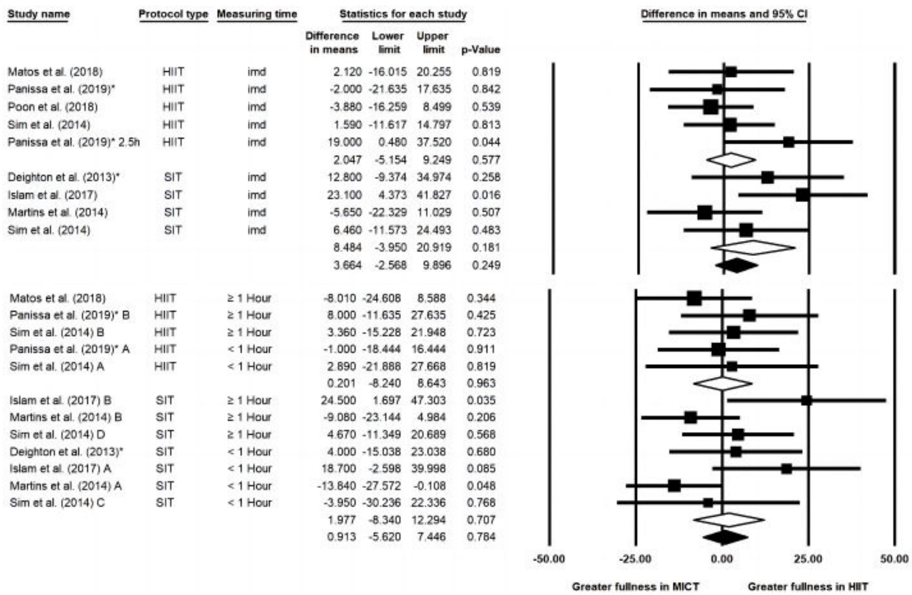

Fig. 5. Effects of HIIT/SIT vs. MICT on fullness perception immediately post exercise.

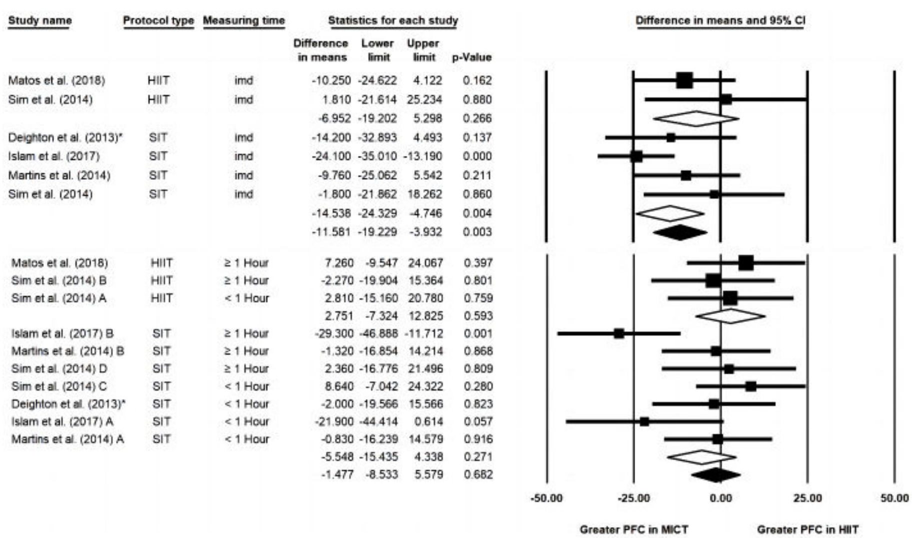

Fig. 6. Effects of HIIT/SIT vs. MICT on prospective food consumption (PFC) immediately and 30–90 min post exercise.

analysis suggested no statistical differences in AUC values of appetite ratings and hunger, fullness, and satisfaction perceptions immediately after acute HIIT/SIT and MICT. Collectively, the results demonstrated the transient effect of exercise (i.e., HIIT/SIT and MICT) on appetite, and interval trainings with higher intensity might lead to greater suppression in hunger.

Our findings extended the previous notion that exercise intensity might affect appetite sensations (Hazell et al., 2016; Hazell, Islam, et al., 2017; Islam et al., 2017) by demonstrating that exercise modalities with varied intensity (i.e., HIIT/SIT and MICT) could have also resulted in dissimilar appetite responses, in a way that HIIT/SIT with higher intensity could suppress hunger more than MICT with lower intensity. Given that a lack of differences in hunger immediately post-exercise, but significant differences were found 30- to 90-min post-exercise, HIIT/SIT might induce a more prolonged effect on appetite regulation than MICT. In support of this speculation, the relationship between exercise intensity and the speed of gastric emptying was found in a previous meta-analysis, suggesting that gastric emptying was faster after lower-intensity exercise but was slower after higher-intensity exercise (Horner, Schubert, Desbrow, Byrne, & King, 2015). It is important to note that more pronounced effects of SIT on appetite suppression compared to HIIT and MICT were observed in the meta-analyses, which might be explained by the intensity-dependent effects of exercise on plasma concentrations of appetite regulating hormones (Hazell et al., 2016), and these hormones were proposed to be mechanical influences of the speed of gastric emptying (Horner et al., 2015). For example, significantly lower levels of active ghrelin, which acts as an orexigenic hormone that stimulates appetite, were observed after SIT compared to MICT (Deighton, Barry, et al., 2013; Larsen et al., 2019; Sim et al., 2014). Nevertheless, future systematic reviews and meta-analyses are needed to ascertain the differences between HIIT/SIT and MICT, considering the inconsistent results regarding anorexigenic hormones (e.g., glucagon-like peptide-1 and polypeptide YY) reported in previous individual studies (Deighton, Barry, et al., 2013; Hazell et al., 2016; Martins et al., 2015; Matos et al., 2018).

It should be considered that the effects of exercise on appetite were not consistent across the four subscales, namely hunger, fullness, prospective food consumption (PFC), and satisfaction. For instance, significant effects of interval protocols compared to MICT were observed in the subscale of PFC immediately post exercise, but there were no significant differences between the two exercise modalities in the other three subscales of appetite. The inconsistency might be explained by the uneven numbers of study arms in each analysis of the four subscales. Moreover, it has been argued that appetite perceptions are not tangible and a simple statement of "I think I can eat a lot" (PFC) could be an aggregate description impacted by objective (unconditioned, or physiological) and subjective (conditioned, or learned) factors (Stubbs et al., 2000). In the present study, greater PFC in MICT compared to HIIT immediately post exercise might result from larger time investment and consequently greater compensatory desire for a larger amount of food in MICT despite similar physiological cues (i.e., empty stomach). However, these sensations could be short-lived and do not necessarily translate to actual subsequent energy intake, which is supported by a recent meta-analysis showing no significant differences between MICT and HIIT on energy intake (Rossi et al., 2022).

Evidence has shown that individual characteristics, such as gender, age, fitness level, body weight, and body composition could affect appetite and EI after exercise (Howe et al., 2014). Despite the variations in individual characteristics (i.e., inclusion of active and inactive, normal-weight and overweight, young and middle-aged individuals) presented in the meta-analyses of the current study, no significant impact from these variations was observed given considerably low heterogeneity levels in most outcomes. However, the impact of sex on appetite to HIIT/SIT and MICT could not be confirmed by the current study, since the majority of the participants in the included studies were men. Nevertheless, in two out of the included 15 studies that recruited participants of both genders, no significant differences were found between different gender groups (Hazell, Townsend, et al., 2017; Panissa et al., 2016). Moreover, the impact of variations in body composition on appetite remains to be investigated, as the results of the body composition of the participants (e.g. fat mass percentage) were often not reported in the studies analyzing appetite and EI.

Exercise timing is another variable that could influence appetite, as the longer time interval between the exercise bout and the meal might result in greater appetite (Albert, Drapeau, & Mathieu, 2015; Panissa et al., 2019). However, the impact of exercise timing could not be clearly demonstrated by the available data from the included studies. The majority of the included studies adopted a similar study design, which mimics the situation where exercise was performed 1 h after breakfast. In one included study that compared appetite sensations after HIIT and MICT completed 15 min or 105 min before lunch, the greatest suppression in appetite was observed in the HIIT session completed 15 min before lunch (Panissa et al., 2019). Moreover, food preloads with varied energy density and nutrition composition might also impact subsequent appetite after exercise (Rouhani, Surkan, & Azadbakht, 2017). Despite low heterogeneity in the meta-analyses, there were still some variations across studies in the energy and nutrient content of the breakfast provided as presented in Table 1, which should be taken into account when interpreting the outcomes.

There were some issues worthy of mention regarding the outcomes of the current review. Firstly, our results of the meta-analyses demonstrated appetite responses within a short period after exercise (i.e., immediately post to 90-min post exercise) and before lunch. In one of 15 included studies that involved a whole-day experiment with measurements performed several hours after the exercise (i.e., in the afternoon), elevated hunger perceptions were observed in SIT compared with MICT during the afternoon (Deighton, Barry, et al., 2013). Secondly, although we attempted to investigate appetite over a period of time after exercise by combing appetite ratings 30- to 90-min post exercise, the influences from changes in gut hormones and other physiological processes should be noted. Nevertheless, the experimental conditions (i.e., HIIT/SIT, MICT, and CON) in each included study were compared at the same timepoint (e.g., at 30-min post exercise). Thirdly, the results of the current review mainly showed the acute responses to HIIT/SIT compared with MICT on appetite responses, given that very few studies have examined the long-term effects of HIIT/SIT and MICT on appetite and EI. Despite that the only two long-term studies reported no differences between HIIT/SIT and MICT after 12-week interventions (Martins et al., 2017; Sim, Wallman, Fairchild, & Guelfi, 2015), more studies are needed to make conclusions on the long-term impact of the intensity and exercise modality. Lastly, to comprehensively examine the effects of HIIT/SIT on appetite sensations, alterations in eating behavior, for example, food preferences or selection of specific nutrients and tastes, should be taken into consideration (King et al., 1997; Zheng, Lenard, Shin, & Berthoud, 2009). Nevertheless, in one of the included studies that reported the desire to eat specific foods along with other more frequently analyzed parameters of appetite sensations (e.g., hunger), no significant differences were found between a bout of HIIT and MICT (Panissa et al., 2019). Similarly, food preference and reward after a 12-week intervention were not altered by HIIT differently compared with MICT, as reported in one of the two long-term studies included in the current review.

In conclusion, the present review showed that both HIIT/SIT and MICT induced lower appetite ratings and relative EI compared to no-exercise control groups in a transient manner and provided some evidence to support the intensity-dependent appetite responses by demonstrating that acute HIIT/SIT could induce lower levels of hunger perceptions and greater satiety sensations compared to MICT after a short period post exercise.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2022.106427.

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