Obesity Comorbidity/Treatment

Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis

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Summary

Background: The scientific interest in high-intensity interval training (HIIT) has greatly increased during recent years.
Objective: The objective of this meta-analysis was to determine the effectiveness of HIIT interventions on cardio-metabolic risk factors and aerobic capacity in overweight and obese youth, in comparison with other forms of exercise.
Data sources: A computerized search was made using seven databases.
Study eligibility criteria: The analysis was restricted to studies that examined the effect of HIIT interventions on cardio-metabolic and/or aerobic capacity in pediatric obesity (6–17 years old).
Participants and interventions: Nine studies using HIIT interventions were selected ($n = 274$).
Study appraisal and synthesis methods: Standarized mean difference (SMD) and 95% confidence intervals were calculated. The DerSimonian–Laird approach was used.
Results: HIIT interventions (4–12 week duration) produced larger decreases in systolic blood pressure (SMD = 0.39; −3.63 mmHg) and greater increases in maximum oxygen uptake (SMD = 0.59; 1.92 ml/kg/min) than other forms of exercise. Also, type of comparison exercise group and duration of study were moderators.
Conclusions: HIIT could be considered a more effective and time-efficient intervention for improving blood pressure and aerobic capacity levels in obese youth in comparison to other types of exercise. © 2016 World Obesity
Keywords: Cardiorespiratory fitness, childhood obesity, intermittent training, intensity training.

Abbreviations; BMI; body mass index, HIIT; High-intensity interval training, HOMA-index; homeostatic model assessment, PRISMA; Preferred Reporting Items for Systematic Reviews and Meta-Analyses, RCT; randomized controlled trials, SMD; standardized mean difference, VO_{2max}; maximal oxygen consumption, WMD; weighted mean difference,

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Introduction

Physical activity has multiple health benefits across several populations (1), and is a critical component in managing pediatric obesity. Indeed, the WHO guidelines recommend that children and young people (5–17 years) engage in 60 min or more of daily physical activity, mainly aerobic, and mainly moderate or vigorous in intensity. Furthermore, it is also recommended that children participate in activities that strengthen the musculoskeletal system at least three times a week (1). However, one of the main barriers to achieving regular physical activity in overweight youth today is lack of time (2). Therefore, the effectiveness of alternative forms of physical activity needs to be considered, especially in terms of this youth population. Studies have recently addressed this lack of time through high-intensity exercise programmes, which reduce the time required to exercise in comparison to low intensity programmes (3).

Although continuous moderate-intensity aerobic exercise have traditionally been shown to generate improvements in some cardiometabolic risk factors (fasting insulin, glucose, systolic and diastolic blood pressure, and lipid profile) (4–6) and aerobic capacity (VO_{2max}) (7) in obese youth, high-intensity interval training (HIIT) has increased greatly in popularity over the last years. These latter programmes consist of high-intensity exercise bouts interspersed by interval rest periods between each set (3). Several studies in adults have reported advantages of HIIT over continuous aerobic exercise at improving aerobic capacity and health in both healthy (8) and obese people (9). Regarding young people, a recent review reported that HIIT delivers similar or greater benefits to the cardiometabolic profile than does steady-state exercise, even after a much shorter total exercise duration (10). Some of the literature extends to obese populations, but results are inconsistent, showing more (11) or similar (12) benefits in comparison to continuous aerobic exercise. Prescribing HIIT consists of manipulating some of at least nine variables (e.g. work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, between-series recovery duration, and intensity) (13). For this reason, the HIIT interventions for overweight and obese children are heterogeneous and, to date, the most suitable combination for maximizing health improvements is not known. Although there are a number of studies that aim to evaluate the effectiveness of HIIT on improving cardiometabolic risk in children and adolescent, because of the heterogeneity of their methodologies, the evidence that each of these studies provide did not seems sufficient to make recommendations; therefore, it appears necessary to take a first approach using the meta-analysis methodology in order to summarize the results found so far, because practitioners urgently demand this information to advice obese children and their families. This is especially relevant because of the increased interest in this kind of exercise in recent years, and the alarming children's obesity prevalence figures (14). This data of this meta-analysis could help researchers to identify the limitations in the studies to conduct new HIIT interventions in children with several risk factors for health. Thus, the aim of this meta-analysis of randomized trials was to determine the effectiveness of HIIT interventions on cardiometabolic risk and aerobic capacity in overweight and obese youth compared with other forms of exercise.

Methods

The study was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (15).

Literature search

Articles published before November 10, 2015, were retrieved by using searches of the CINAHL (1937– November 10, 2015), Cochrane Central Register of Controlled Trials (CENTRAL) (2002– November 10, 2015), EMBASE (1980– November 10, 2015), ERIC (1966– November 10, 2015), MEDLINE (1965– November 10, 2015), PsycINFO (1987– November 10, 2015) and Science Citation Index (1990– November 10, 2015) online databases. The search strategy included the topic's specialist journals. The search was conducted between the 4th and the 10th of November 2015. The terms used were: ['*Obesity*' and '*Overweight*' OR], ['*High-intensity interval training*' and '*High-intensity interval exercise*' and '*High-intensity intermittent exercise*']. All Medical Subject Headings terms were combined with body composition*, cardiometabolic*, aerobic capacity* and the following limiters: age (all children and adolescents 6–17 years old) and publication type (randomized controlled trials [RCT]). Also, the reference lists were examined to detect studies potentially eligible for inclusion. All languages were accepted.

Study selection and inclusion criteria

Two authors (AG-H and AJC-U) independently screened the titles and abstracts of potentially eligible studies identified by the search strategy. Discrepancies between the two reviewers about study conditions were resolved by consensus with a third author (JMS). The inclusion criteria were as follows: (a) children and/or adolescents (6–17 years old) classified as overweight or obese; (b) RCT studies; (c) interventions of HIIT, prescribed high intensity exercise (e.g. 64–90% VO_{2max} or 77–95% heart rate max) (16); (d) ≥4 weeks in duration, with or without nutrition or lifestyle intervention; a comparison exercise group; and (e) evaluations of body composition (in at least one of the following areas): body weight, body mass index (BMI), fat mass (% or kg), waist circumference; (e.i) cardiometabolic risk variables (at least one of the following): total cholesterol, high-density lipoprotein, low-density lipoprotein, triglycerides, fasting glucose, insulin, homeostatic model assessment (HOMA-index), systolic blood pressure and/or diastolic blood pressure; and/or (e.ii) aerobic capacity assessed as VO_{2max}. No exclusion criteria in terms of work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, between-series recovery duration or intensity were taken into account.

Data collection

Data was extracted regarding the characteristics of participants, exercise programmes, assessments and results. A request asking for missing data (body composition, cardiometabolic risk variables and/or aerobic capacity) was sent to each of the corresponding authors. Only one of the three authors we contacted provided us with the missing data (17).

Risk of bias

Two authors (AG-H and AJC-U) independently assessed the risk of bias for each of the included studies in accordance with The Cochrane Collaboration recommendations (18). The risk of bias assessment in RCT was performed using the Review Manager programme (Update Software, Oxford) (18,19). This technique sets seven criteria as indicators of the quality of trials according to the responses 'low risk', 'high risk' or 'unclear'.

Meta-analysis calculation

For the data analysis, we used Review Manager (Update Software, Oxford) to calculate the standardized mean difference (SMD) and the weighted mean difference (WMD). The SMD and WMD of the body composition, cardiometabolic variables and aerobic capacity from pre- to post-intervention between groups (HIIT vs. other forms of exercise) (20) in each study was calculated and pooled using the random-effects model (DerSimonian–Laird approach). The underlying assumption of the random-effects model is that samples are drawn from populations with different effect sizes, and that true effects differ between studies (interventions, duration, etc.).

Assessment of heterogeneity

The percentage of total variations across the studies because of heterogeneity (Cochran's Q-statistic) (21) was determined using I^2. I^2 values of <25%, 25–50% and >50% are considered to represent small, medium and large amounts of inconsistency (22).

Publication bias and sensitivity

Each study was deleted from the model once in order to analyse the influence of each study on the overall results. The funnel plot and the Egger test were used to examine publication bias (23).

Subgroup moderator analyses

The following subgroup moderator analyses were conducted xaccording to type of comparison exercise group (i.e. moderate-intensity continuous training) and duration of study (i.e. ≥12 weeks). Moderator effects were considered significant at $p < 0.10$.

Meta-regression

Also, where significant results were found, meta-regression analyses were performed to determine the relationship between bouts, recovery duration and baseline values with changes observed in SBP and VO_{2max}. Additionally for these cases, the relationship between changes in VO_{2max} and SBP was analysed.

Results

Study selection

Titles and abstracts of 50 full-text retrieved articles were searched for suitability. Of those, 41 did not fulfil inclusion criteria: seven failed on participants' profile criterion; 31, on type of intervention criterion (multicomponent programmes or exercise) and three did not include a comparative exercise group. The total number of papers included in the analysis was nine (Fig. 1).

Study characteristics and participants

The characteristics of the RCT are summarized in Table 1 (11,12,17,24–29). The final analysis included a total of 274 youth (192 boys, 70.0%). Subjects were overweight/obese (11,26) or obese (12,17,24,25,27–29). Several criteria were used to define overweight and obese: Centers for Disease Control (≥95p) (17), First National Health and Nutrition Examination Survey (≥95p) (12), International Obesity Task Force (≥97p) (24,26,28), and Chinese (≥95p) (29) or French (≥97p) (25) nation-specific criteria for the child population. The remaining studies did not provide information regarding the criteria that they used to categorize participants as overweight or obese (11,27).

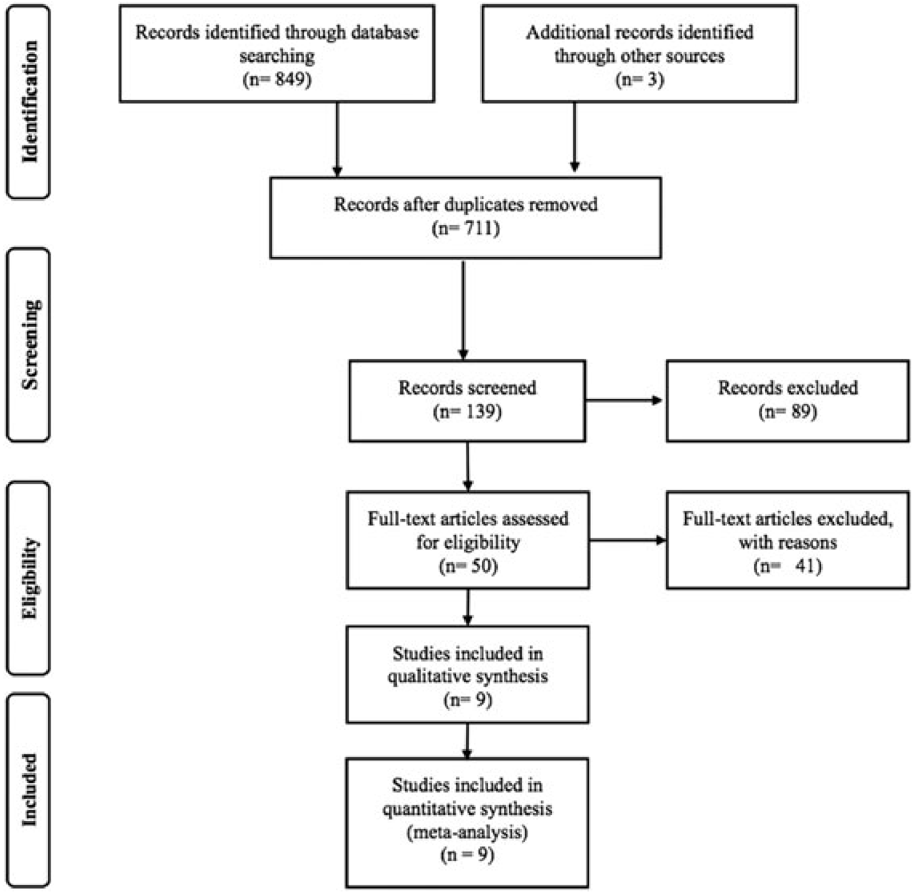

Figure 1 Flow chart for identification of trials for inclusion in the meta-analysis.

High-intensity interval training programme characteristics

The programmes mainly used walking and running (11,12,24,29), only running (25,26,28), or cycling (17). The protocols used in the studies were heterogeneous: for example, the number of bouts ranged from 2 (28) to 12 (26), and the frequency was from 2 (11,12,29) to 4 (25) sessions per week. Regarding the duration of bouts, exercises were carried out for between 15 seconds (26) to 4 min (11) with passive or active recovery between repetitions (15 s to 3 min). Intensity exercise was performed at between 100% (28) and 120% (26) maximum aerobic speed, between 80% (27) and 95% (11,17,29) maximal heart rate, between 80% and 90% VO_{2max} (25) and at 100% maximum velocity sprint (12). The total time of the session, calculated by multiplying the number of high-intensity intervals × interval length × recovery length, were between 18 and 45 min (mean 29 min). The duration of the interventions was 12 weeks, except for three studies, which lasted 4 (27) or 6 weeks (17,26). Finally, six studies used active recovery (11,12,17,27–29), two passive recovery (25,26) and one unknown (24) (Table 1). Adherence to the training programmes was only reported in five studies (11,12,17,24,27), and in all of them was greater than 80%, except one that reported adherence lower than 45% (24).

Exercise group characteristics

The main content of the exercise groups programmes was similar to that of HIIT, based on treadmill walking, cycling, or running. The mode of exercise was continuous (11,12,17,25,29) or interval training at moderate (27,28) or low intensity (24,26). The duration of the exercise sessions ranged from 30 to 60 min (mean 45 min), and the intensity was from 60% to 80% of the youth's maximal aerobic capacity (maximum heart rate, VO_{2max} or maximum aerobic speed).

Methodological quality of studies

The overall quality of the RCTs was low. Six RCTs had quality indicators that were all of 'low risk' for or 'unclear' bias, and were considered to be of average quality

Table 1 Studies examining the effect of HIIT on body composition, cardiometabolic risk factors and aerobic capacity

Study	Subjects (*n*)	Groups	Group size	Modality / intensity	Bouts/frequency	Bouts duration	Recovery	Total time (min)	Intervention duration	Low risk of bias (*n*)
Corte de Araujo [13]	30 (9 boys, 21 girls; 8–12 years of age)	HIIT	15	Treadmill running / 100% maximum velocity sprints	Up to 6 / 2 weekly	1 min	3-min active recovery at 50% maximum velocity	18	12 weeks	5
		CG	15	Continuous treadmill walking/running /80% peak HR	2 weekly	30 min (increased by 10 min every 3 weeks)	—	30–60		
Farah [24]	43 (9 boys, 10 girls; 13–18 years of age)	HIIT	9	Treadmill running / ventilator threshold	Unknown / 3 times weekly	Energy expenditure set at 350 kcal	Unknown	Unknown	24 weeks	5
		CG	10	Treadmill running / <20% ventilator threshold	3 times weekly					
Kouba [25]	29 (13 ± 0.8 years of age)	HIIT	14	Running / 80% VO_{2max}, increased by 5% every 4 weeks	Unknown / 3 times weekly	2 min	1 min passive recovery	Unknown	12 weeks	3
		CG	15	Continuous running / 60–70% VO_{2max}	3 times weekly	30 min	—	30		
Lau [26]	48 (36 boys, 12 girls; 10.4 ± 0.9 years of age)	HIIT	21	Running / 120% maximum aerobic speed	12 / 3 times weekly	15 s	15 s of passive recovery	4560	6 weeks	3
		CG	15	Running / 100% maximum aerobic speed	16 / 3 times weekly	15 s	15 s of passive recovery			
Murphy [27]	13 (3 boys, 15 girls; 12–18 years of age)	HIIT	76	Unknown / 80–90% MHR	10 / 4 times weekly	1 min	2 min of active recovery at 60% at MHR	2050	4 weeks	1
		CG		Unknown / 65% MHR	4 times weekly	50 min	—			
Racil [28]	34 (15.9 ± 0.3 years of age)	HIIT	11	Shuttle runs / 100–110% maximum aerobic speed	Two blocks of up to 8 bouts / 3 times weekly	30 s	30 s active recovery at 50% maximum aerobic speed with 4 min rest between blocks	20	12 weeks	4
		CG	12	Shuttle runs / 70–80% maximum aerobic speed						
Starkoff [17]	34 (10 boys, 17 girls; 14.7±1.5 years of age)	HIIT	18	Cycling / 90–95% MHR	10 / 3 times weekly	2 min	1 min of active recovery at 55% at MHR	30	6 weeks	5
		CG	16	Cycling / 65–70% MHR	3 times weekly	30 min		30		
Tjonna [11]	54 (26 boys, 28 girls; 14 years of age)	HIIT	28	Treadmill walking–running / 90–95 % MHR	4 / 2 times weekly	4 min	3 min active recovery at 70% at MHR	40	12 weeks	4
		CG	26	Multitreatment	Unknown	—	—	Unknown		
Xiuming [29]	70 (70 boys; 8–12 years of age)	HIIT	36	Treadmill walking–running / 90–95% MHR	3–6 / 2 times weekly	1 min	1 min of active recovery at 50% at MHR	10–30	12 weeks	3
		CG	34	Treadmill walking–running / 80% MHR	2 times weekly	30–60 min	—	30–60		

p = percentile, CG, comparison exercise group; HIIT, high-intensity interval training; MHR, maximum heart rate; min, minutes.
*Overweight and obese.

(12,17,24–26,28,29); the remaining two studies, with some quality indicators that were 'high risk,' were considered to be low quality (11,27). All RCTs reported a process of randomization. Blinding was unknown in seven studies (12,24–28). In one study, the results data was insufficient, and selective outcomes were reported (27). In another study, other potential threats to valid were found (11) (Fig. S1).

Body composition assessments

The methodologies of assessment were different. Weight measure was assessed using a medical scale and WC using the standard protocol. Body composition was assessed using four methods: bioelectrical impedance (12,27,28), dual-energy x-ray absorptiometry (DEXA) (11), air displacement plethysmography (17) and skinfolds (24–26). Because of the different methodologies, the results presented should be analysed with caution. For example, as compared with DEXA, there appears not to be simple, non-invasive and accurate method for measuring changes in children's percentage body fat, while air-displacement plethysmography has better performance than skinfolds or bioelectrical impedance (30).

Cardiometabolic risk factor assessment characteristics

Biochemical analysis: the evaluations were made in the morning after 12 h (12,24,25,28,29) of overnight fasting. The remaining study did not provide this information (11). Blood pressure: various methods were used to determine blood pressure. Most employed a sphygmomanometer (manual or electronic) and an appropriately sized cuff (12,24,29), and another study used high-resolution vascular ultrasound (flow mediated dilation) (11). The remaining study did not provide this information (25).

Aerobic capacity assessment

VO_{2max} was determined by a maximal (11,24,25,27,28) or submaximal (17) effort test on treadmill (11,24,27), cycloergometer (17) or field test (using a gas analysing portal device) (25,28).

Meta-analysis

Differences between HIIT and other forms of exercise were observed for systolic blood pressure (SMD = 0.39, 95% CI 0.09 to 0.69; $p = 0.01$; $I^2 = 1\%$; WMD = −3.63 mmHg) (greater reduction with HIIT programmes) (Fig. 2). Also, data showed VO_{2max} with HIIT programmes had a higher increase (SMD = 0.59, 95% CI 0.17 to 1.01, $p = 0.006$; $I^2 = 35\%$; WMD = 1.92 ml/kg/min) (Fig. 3) than other forms of exercise (Table 2) (Fig. S2, S3, S4).

Subgroup moderator analyses

Type of comparison exercise group was a moderator for the effect on VO_{2max}, with larger effects observed for studies that included a comparison, moderate-intensity continuous training group (SMD = 0.70, 95% CI, 0.29 to 1.11; $p < 0.001$; $I^2 = 0\%$; WMD = 2.62 ml/kg/min^{-1}) (Table S1) in contrast to those that included a comparison, moderate-intensity interval training group ($p = 0.35$) (data not shown).

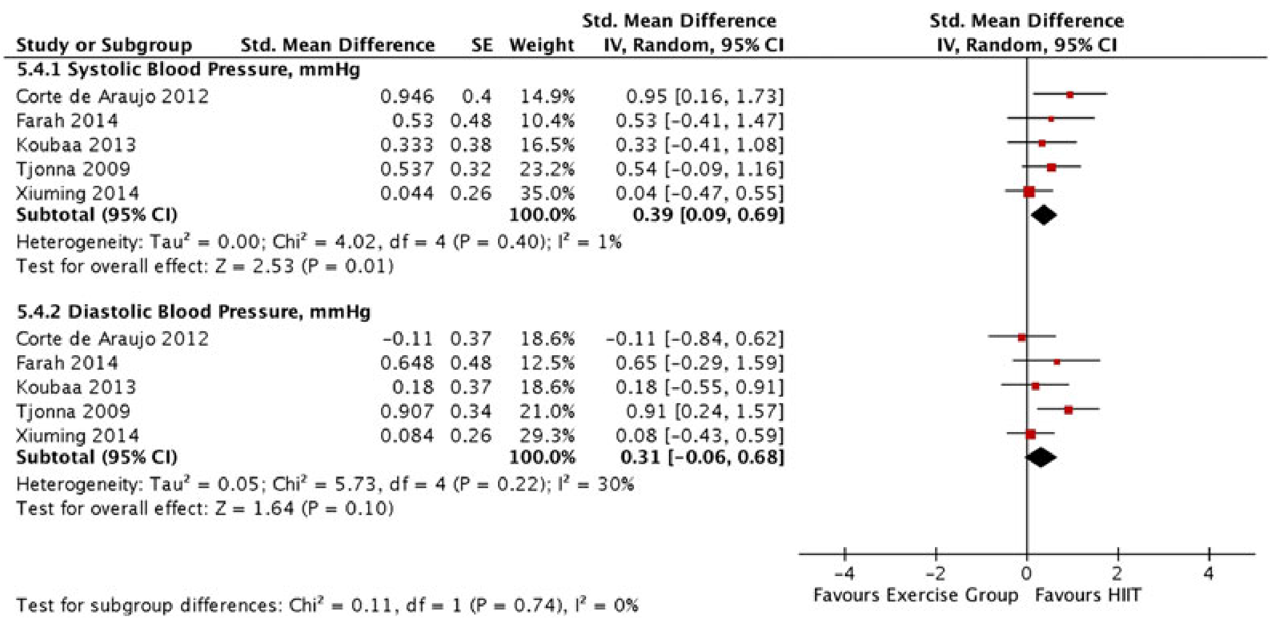

Figure 2 Forest plot of mean difference in blood pressure variables of studies included. CI confidence interval, HIIT high-intensity interval training, IV inverse-variance, SE standard error.

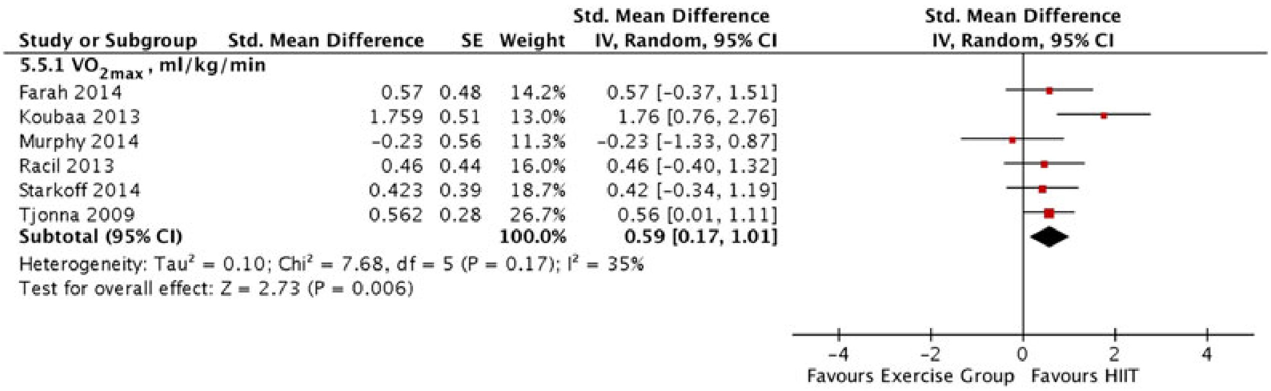

Figure 3 Forest plot of mean difference in aerobic capacity (VO_{2max}) of studies included. CI, confidence interval; HIIT, high-intensity interval training; IV, inverse-variance; SE, standard error.

Table 2 Effects of HIIT programmes compared to other exercise modalities on body composition, cardiometabolic risk factors and aerobic capacity

	Study (*n*)	Subjects (*n*)	SMD (95% CI)*	*p*	I^2 (%)
Body composition					
Weight, kg	8	274	0.06 (−0.19, 0.30)	0.650	0
Body mass index, kg/m^2	8	274	−0.02 (−0.26, 0.23)	0.881	0
Waist circumference, cm	6	154	0.07 (−0.29, 0.43)	0.701	24
Fat mass, %	6	138	0.16 (−0.16, 0.48)	0.323	0
Fat mass, kg	3	86	−0.03 (−0.43, 0.48)	0.875	0
Lipids and lipoprotein					
Total cholesterol, mmol/L	4	141	0.09 (−0.24, 0.43)	0.585	0
HDL, mmol/L	4	168	0.26 (−0.48, 1.00)	0.491	81
LDL, mmol/L	4	141	−0.06 (−0.52, 0.39)	0.794	41
Triglycerides, mmol/L	5	168	0.19 (−0.11, 0.49)	0.221	2
Insulin resistance					
Fasting glucose, mmol/L	4	139	0.43 (−0.15, 1.02)	0.154	68
Fasting insulin, µU/mL	5	158	0.23 (−0.07, 0.52)	0.131	0
HOMA-index	4	131	0.39 (−0.13, 0.91)	0.144	48
Blood pressure					
Systolic blood pressure, mmHg	5	165	**0.39 (0.09, 0.69)**	**0.010**	1
Diastolic blood pressure, mmHg	5	165	0.31 (−0.06, 0.68)	0.103	30
Aerobic capacity					
VO_{2max}, mL/kg/min	6	137	**0.59 (0.17, 1.01)**	**0.006**	35

VO_{2max}, maximal oxygen consumption; SMD, standarized mean difference. Bold indicates statistical significance ($p < 0.05$)
*Positive effect sizes indicate values that favour HIIT group.

Also, duration of the study moderated the effect of HIIT on VO_{2max}, with larger effects observed in studies ≥12 weeks (SMD = 0.70, 95% CI, 0.32 to 1.06; $p < 0.001$; $I^2 = 0\%$; WMD = 1.98 ml/kg/min^{-1}) (Table S1), as compared to those <12 weeks ($p = 0.58$) (data not shown).

Meta-regression

Duration of the bout (SBP: $\beta = 0.11$, $p = 0.399$; VO2max: $\beta = 0.72$, $p = 0.119$), recovery time (SBP: $\beta = 0.28$; $p = 0.083$; VO2max: $\beta = 0.64$, $p = 0.336$), and baseline level (SBP: $\beta = 0.03$, $p = 0.133$; VO2max: $\beta = 0.01$, $p = 0.910$) did not predict the observed improvements in SBP and VO_{2max}. Also, changes in VO_{2max} did not predict the observed improvements in SBP ($\beta = 0.09$, $p = 0.411$).

Publication bias and sensitivity analysis

Both funnel plot asymmetry and Egger test show no significant publication bias for any of the outcome variables. Regarding sensitivity analysis, results remained the same across all deletions.

Discussion

The present study is the first meta-analysis to analyse the effectiveness of HIIT interventions on improving cardiometabolic risk and aerobic capacity in overweight and obese youth compared with other forms of exercise. On this, the meta-analysis showed that HIIT programmes generate greater reductions in systolic blood pressure and increases in VO_{2max} in overweight and obese youth than other forms of exercise (moderate-intensity continuous training, moderate-intensity interval training and low-intensity interval training). Type of comparison exercise group and duration of study were moderators for the effect of HIIT on VO_{2max}. Therefore, the findings suggest that HIIT interventions induced more favourable adaptations in the central and peripheral cardiovascular system as compared with other forms of exercise.

Previous research has shown that HIIT (compared with non-exercise control group) is a highly effective exercise method in improving indexes of health in both adults (31) and youth (32,33). However, in overweight and obese youth populations, evidence is not clear enough when comparing HIIT to other forms of exercise (8,12). According to this meta-analysis, HIIT interventions produced greater decreases in systolic blood pressure (SMD = 0.39; WMD = −3.67 mmHg; $p = 0.010$) compared to other forms of exercise. In adolescents, greater vascular benefits have been reported when performing HIIT than with moderate-intensity continuous training (34). Although the responsible mechanisms have not been fully elucidated, high-intensity physical activity could generate a higher reduction of sympathetic nervous activity (35) and increased nitric oxide-mediated vasodilatation (36) than might moderate-intensity continuous training. Another hypothesis that could explain these adaptations is the shear vascular stress induced by higher intensity exercise (37).

Further, several studies with HIIT programmes have consistently shown a greater increase in VO_{2max} than have studies on other exercise modalities in healthy adults (38), in those with cardiometabolic diseases (39) and in adolescents (40). Compared with a non-exercise control group, a recent RCT in obese and healthy children reported that six weeks of HIIT, using games-based exercises, demonstrated an improvement of aerobic capacity (32). Overall, the present meta-analysis shows that HIIT has a greater positive influence on aerobic capacity than do other forms of exercise (SMD = 0.59; WMD = 1.92 ml/kg/min; $p = 0.006$). Our results extend a previous meta-analysis that examined the effect of aerobic exercise on fitness for obese children, which reported statistically significant moderate effects for VO_{2max} (SMD = 0.46) in comparison to a non-exercise control group (7). VO_{2max} is an important marker of cardiometabolic health, and is associated with decreases in morbidity and mortality risks in the general population (41). In the same way, VO_{2max} levels in youth predict cardiovascular disease in later life (34).

Although it has been shown that aerobic exercise improves VO_{2max} in obese children (7), high-intensity exercise seems to be associated with greater benefits (42). Several authors have described VO_{2max} as improving through HIIT programmes because of an increase in oxygen availability as seen from central effects (such as maximal cardiac output, total hemoglobin and blood plasma volume) (43) and/or as a consequence of peripheral adaptations with an improved ability to extract and use available oxygen because of increased muscle oxidative potential (44). However, adaptations in muscles' mitochondrial enzymes alone cannot explain the changes in VO_{2max} because enzymatic changes are sometimes more pronounced than the related improvement in this aerobic capacity parameter (44). Similarly, the effect of HIIT programmes on skeletal muscle oxidative potential has been shown to be more pronounced in comparison with aerobic programmes (moderate-intensity continuous training) (45). Indeed, when compared to moderate-intensity continuous training, HIIT elicits a large improvement in aerobic capacity (SMD = 0.74; WMD = 2.62 ml/kg/min; $p = 0.003$). Confirming the results of the current work, two recent meta-analyses in adults showed that HIIT has a greater positive influence on aerobic capacity than does moderate-intensity continuous exercise (endurance training) (8,46). Also, study duration emerged as a moderator for VO_{2max}, indicating greater effects in HIIT interventions of $\geq$12 weeks (SMD = 0.70; WMD = 1.98 ml/kg/min; $p = 0.035$) in comparison to those that included <12 weeks. However, given the quality of studies in the current subgroup of meta-analysis, coupled with the small sample size, further research is still warranted to determine the optimal HIIT for enhancing aerobic capacity.

The present meta-analysis has certain limitations that should be noted: (i) Some of the included RCT had some methodological pitfalls that did not affect the internal validity of the studies, thus they met inclusion criteria and did not influence the consistency and relevance of the results of the meta-analysis; (ii) the methods used to determine health indicators were different, and their variation coefficients would probably be high; (iii) Despite the short length of the programmes, in most similar studies this length is considered sufficient to achieve the maximal trainability of participants; (iv) little is known regarding the feasibility of implementing HIIT outside of a laboratory setting – that said, a recent RCT using HIIT games-based exercise demonstrated an improvement in several health variables in healthy and obese children (32).

In summary, this meta-analysis provides insight into the higher effectiveness of short-term HIIT interventions on improving aerobic capacity and blood pressure, especially as compared to moderate-intensity continuous training, and especially with interventions that last more than 12 weeks. In the other health variables, these programmes seem to be a similarly effective alternative (and more time-efficient strategy), with a much lower volume of activity and potentially reduced time commitment (29 vs 45 min of duration in HIIT vs other forms of exercise, respectively). Finally, a study has reported that HIIT is perceived as a more enjoyable exercise compared to other exercise modalities (32), which would have implications for participation in adherence to this type of activity, which could favour greater autonomous motivation (47).

Conflict of interest

Authors declare that they have no conflict of interest.

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Supporting information

Additional supporting information may be found in the online version of this article at publisher's website.

Fig. S1. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Fig. S2. Forest plot of mean difference in body composition variables of studies included. CI confidence interval, HIIT high-intensity interval training, IV inverse-variance, SE standard error.

Fig. S3. Forest plot of mean difference in lipid and lipoprotein of studies included. CI confidence interval, HIIT high-intensity interval training, IV inverse-variance, SE standard error.

Fig. S4. Forest plot of mean difference in insulin resistance variables of studies included. CI confidence interval, HIIT high-intensity interval training, IV inverse-variance, SE standard error.

References

1. WHO. *Global Recommendations on Physical Activity for Health*. World Health Organization: Geneva, 2010.
2. Zabinski MF, Saelens BE, Stein RI, Hayden-Wade HA, Wilfley DE. Overweight children's barriers to and support for physical activity. *Obes Res* 2003; **11**: 238–246.
3. Gibala MJ, Little JP, MacDonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol* 2012; **590**: 1077–1084.
4. García-Hermoso A, Saavedra J, Escalante Y. Effects of exercise on resting blood pressure in obese children: a meta-analysis of randomized controlled trials. *Obes Rev* 2013; **14**: 919–928.
5. García-Hermoso A, Saavedra JM, Escalante Y, Sánchez-López M, Martínez-Vizcaíno V. Aerobic exercise reduces insulin resistance markers in obese youth: a meta-analysis of randomized controlled trials. *Eur J Endocrinol* 2014; **171**: 163–171.
6. Escalante Y, Saavedra JM, García-Hermoso A, Domínguez AM. Improvement of the lipid profile with exercise in obese children: a systematic review. *Prev Med* 2012; **54**: 293–301.
7. Saavedra JM, Escalante Y, García-Hermoso A. Improvement of aerobic fitness in obese children: a meta-analysis. *Int J Pediatr Obes* 2011; **6**: 169–177.
8. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. *Sports Med* 2015; **45**: 679–692.
9. Lunt H, Draper N, Marshall HC *et al.* High intensity interval training in a real world setting: a randomized controlled feasibility study in overweight inactive adults, measuring change in maximal oxygen uptake. *PLoS One* 2014; **9**: e83256.
10. Logan GR, Harris N, Duncan S, Schofield G. A review of adolescent high-intensity interval training. *Sports Med* 2014; **44**: 1071–1085.
11. Tjonna A, Stolen T, Bye A *et al.* Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. *Clin Sci* 2009; **116**: 317–326.
12. Corte de Araujo AC, Roschel H, Picanço AR *et al.* Similar health benefits of endurance and high-intensity interval training in obese children. *PLoS One* 2012; **7**: 1–8.
13. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle. *Sports Med* 2013; **43**: 313–338.
14. Ng M, Fleming T, Robinson M *et al.* Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014; **384**: 766–781.
15. Liberati A, Altman DG, Tetzlaff J *et al.* The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med* 2009; **6**: 1–28.
16. Garber CE, Blissmer B, Deschenes MR *et al.*. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 2011; **43**: 1334–1359.
17. Starkoff BE, Eneli IU, Bonny AE, Hoffman RP, Devor ST. Estimated aerobic capacity changes in adolescents with obesity following high intensity interval exercise. *Int J Kinesiol Sports Sci* 2014; **2**: 1–8.
18. Higgins JP, Altman DG, Gøtzsche PC *et al.* The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011; **343**: d5928. DOI: http://dx.doi.org/10.1136/bmj.d5928.
19. Savovic J, Weeks L, Sterne J *et al.* Evaluation of the Cochrane Collaboration's tool for assessing the risk of bias in randomized trials: focus groups, online survey, proposed recommendations and their implementation. *Syst Rev* 2014; **3**: 37. DOI: http://dx.doi.org/10.1186/2046-4053-3-37.
20. Morris SB. Estimating effect sizes from the pretest-posttest-control group designs. *Organ Res Methods* 2008; **11**: 364–386.
21. Higgins J, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003; **327**: 557–560.
22. Higgins J, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002; **21**: 1539–1558.
23. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 1997; **315**: 629–634.
24. Farah B, Ritti-Dias R, Balagopal P, Hill J, Prado W. Does exercise intensity affect blood pressure and heart rate in obese adolescents? A 6-month multidisciplinary randomized intervention study. *Pediatric Obesity* 2014; **9**: 111–120.
25. Koubaa A, Trabelsi H, Masmoudi L *et al.* Effect of Intermittent and continuous training on body composition cardio-respiratory fitness and lipid profile in obese adolescents. *IOSR-JPBS* 2013; **3**: 31–37.
26. Lau PW, Wong DP, Ngo JK, Liang Y, Kim C, Kim H. Effects of high-intensity intermittent running exercise in overweight children. *Eur J Sport Sci* 2015; **15**: 182–190.

27. Murphy A, Kist C, Gier AJ, Edwards NM, Gao Z, Siegel RM. The feasibility of high-intensity interval exercise in obese adolescents. *Clin Pediatr* 2015; **54**: 87–90.
28. Racil G, Ounis OB, Hammouda O *et al*. Effects of high vs. moderate exercise intensity during interval training on lipids and adiponectin levels in obese young females. *Eur J Appl Physiol* 2013; **113**: 2531–2540.
29. Xiuming Z. Effects of endurance training and high-intensity interval training on health-related indexs of obese children. *Med J Nat Defend Forces Southwest Chin* 2014; **4**: 408–411.
30. Elberg J, McDuffie JR, Sebring NG *et al*.. Comparison of methods to assess change in children's body composition. *Am J Clin Nutr* 2004; **80**: 64–69.
31. Kemmler W, Scharf M, Lell M, Petrasek C, Von Stengel S. High versus moderate intensity running exercise to impact cardiometabolic risk factors: the randomized controlled RUSH-study. *Biomed Res Int* 2014. DOI: http://dx.doi.org/10.1155/2014/843095.
32. Lambrick D, Westrupp N, Kaufmann S, Stoner L, Faulkner J. The effectiveness of a high-intensity games intervention on improving indices of health in young children. *J Sports Sci* 2015; **26**: 1–9.
33. Baquet G, Berthoin S, Gerbeaux M, Van Praagh E. High-intensity aerobic training during a 10 week one-hour physical education cycle: effects on physical fitness of adolescents aged 11 to 16. *Int J Sports Med* 2001; **22**: 295–300.
34. Bond B, Hind S, Williams CA, Barker AR. The acute effect of exercise intensity on vascular function in adolescents. *Med Sci Sports Exerc* 2015. DOI: http://dx.doi.org/10.1249/MSS.0000000000000715.
35. Halliwill J, Taylor JA, Eckberg DL. Impaired sympathetic vascular regulation in humans after acute dynamic exercise. *J Physiol* 1996; **495**: 279–288.
36. Halliwill JR. Mechanisms and clinical implications of post-exercise hypotension in humans. *Exerc Sport Sci Rev* 2001; **29**: 65–70.
37. Tinken TM, Thijssen DH, Hopkins N, Dawson EA, Cable NT, Green DJ. Shear stress mediates endothelial adaptations to exercise training in humans. *Hypertension* 2010; **55**: 312–318.
38. Helgerud J, Hoydal K, Wang E *et al*. Aerobic high-intensity intervals improve VO_2 max more than moderate training. *Med Sci Sports Exerc* 2007; **39**: 665–671.
39. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *Br J Sports Med* 2014; **48**: 1227–1234.
40. Costigan S, Eather N, Plotnikoff R, Taaffe D, Lubans D. High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. *Br J Sports Med* 2015; **49**: 1253–1261.
41. Berry JD, Willis B, Gupta S *et al*. Lifetime risks for cardiovascular disease mortality by cardiorespiratory fitness levels measured at ages 45, 55, and 65 years in men: the Cooper Center Longitudinal Study. *J Am Coll Cardiol* 2011; **57**: 1604–1610.
42. Gutin B, Barbeau P, Owens S *et al*. Effects of exercise intensity on cardiovascular fitness, total body composition, and visceral adiposity of obese adolescents. *Am J Clin Nutr* 2002; **75**: 818–826.
43. Astorino TA, Allen RP, Roberson DW, Jurancich M. Effect of high-intensity interval training on cardiovascular function, VO2max, and muscular force. *J Strength Cond Res* 2012; **26**: 138–145.
44. Burgomaster KA, Howarth KR, Phillips SM *et al*. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *J Physiol* 2008; **586**: 151–160.
45. Tremblay A, Simoneau J-A, Bouchard C. Impact of exercise intensity on body fatness and skeletal muscle metabolism. *Metabolism* 1994; **43**: 814–818.
46. Milanović Z, Sporiš G, Weston M. Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO2max improvements: a systematic review and meta-analysis of controlled trials. *Sports Med* 2015; **45**: 1469–1481.
47. Saavedra JM, García-Hermoso A, Escalante Y, Domínguez AM. Self-determined motivation, physical exercise and diet in obese children: a three-year follow-up study. *Int J Clin Health Psychol* 2014; **14**: 195–201.

