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High-intensity interval training in overweight and obese children and adolescents: systematic review and meta-analysis

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ABSTRACT

INTRODUCTION. While High Intensity Interval Training is praised in many populations for its beneficial effects on body composition and cardiometabolic health, its use among obese youth remain uncertain. This study aimed at determining whether HIIT is effective to improve aerobic fitness and reduce cardiometabolic risk factors in overweight and obese youth.

EVIDENCE ACQUISITION. A systematic search was conducted and articles reporting studies that investigated the effects of HIIT in 6 to 18-year-old youth were eligible. Meta-analyses were performed when appropriate.

EVIDENCE SYNTHESIS. 15 studies were included for the systematic review and meta-analyses. HIIT significantly improves maximal oxygen uptake [1.117 (95% CI=0.528 to 1.706), p<0.001], and reduces body mass [-0.295 (95%CI =-0.525 to -0.066), p<0.05], body fat [-0.786 (95%CI =-1.452 to -0.120), p<0.05], systolic and diastolic blood pressure [-1.026 (95% CI = -1.370 to -0.683), p<0.001; -0.966 (95% CI =-1.628 to -0.304), p<0.01 respectively], and the HOMA-IR [-1.589 (95%CI =-2.528 to -0.650), p<0.01]. However, there is significant heterogeneity, and low to high inconsistency for most cardiometabolic risk factors and aerobic fitness.

CONCLUSION. Although few studies have reported cardiometabolic risks, HIIT may also be as effective as traditional endurance continuous training to decrease blood pressure and insulin resistance. HIIT is effective to improve aerobic fitness, body composition, and cardiometabolic risk factors in obese youth, but data are insufficient to determine whether it is more effective than traditional continuous submaximal intensity exercise training.

KEYWORDS: High-Intensity Interval Training – Children – Adolescents - Physical fitness - Cardiometabolic health

ABBREVIATION LIST

AIT. Aerobic Interval Training

BMI. Body Mass Index

BF%. Body Mass percentage

BW. Body Weight

ES. Effect sizes

FFM. Fat-Free Mass

HIIT. High-Intensity Intermittent Training

PA. Physical Activity

RCT. Randomized Controlled Trials

SIT. Sprint Interval Training

VO_{2max}. Maximal oxygen uptake

INTRODUCTION

The need for a minimal physical activity (PA) level is now well recognized to prevent or counteract the development of obesity and related cardiometabolic disorders. Unfortunately, the prevalence of children who match the current PA recommendation of 60 minutes per day of moderate to vigorous intensity PA ranges from 7% to 15% in developed countries.[1, 2] There has been a growing interest over the last decade for the physiological effects of high-intensity intermittent exercise training (HIIT), with the hope that this type of exercise would be less time consuming and better tolerated than endurance exercise while providing the same health benefits.[3]

HIIT can take different forms, ranging from Aerobic Interval Training (AIT) to Sprint Interval Training (SIT). AIT has commonly been used by endurance athletes since the beginning of the 20th century to induce improvement in aerobic power (i.e., maximal oxygen uptake, VO_{2max}) that may not be achievable by long-duration continuous low to moderate intensity exercise. AIT typically consists of repetitions lasting 10-seconds to 4-minutes at intensities ranging from ~90 to ~110% VO_{2max} interspersed with passive or active recovery periods of equal duration.[4] SIT typically consists of repeating as few as 4 Wingate-like 30-seconds “all out” sprints, separated by 4 minutes passive recovery periods.[5] Although the duration of SIT training sessions may be similar to that of traditional endurance exercise,[6] the effective duration of supramaximal exercise is far lower compared to traditional endurance exercise.

In adults, Randomized Controlled Trial (RCT) of short-term SIT have shown increased insulin sensitivity in sedentary men,[7, 8] reduced post-prandial triglycerides levels,[9, 10] increased skeletal muscle microvascular density,[7] and activation of mitochondrial biogenesis in healthy adults, or those with Type 2 Diabetes.[5, 11] The growing body of studies on HIIT has provided sufficient data to conduct meta-analyses, with physical fitness parameters,[12, 13] and a systematic review with cardiometabolic parameters [14] as the primary criteria. The overall effect of HIIT on VO_{2max} appears moderate to large when compared to untrained control groups in sedentary and active men and women, and not different from that of traditional endurance training.[12, 13, 15] To date, these investigations have mostly been limited to the adult population.

The benefits of continuous low to moderate intensity exercise training on physical fitness and markers of cardiovascular and metabolic health have also been demonstrated by RCTs conducted in the pediatric population, often focused on obesity and related comorbidities. Several meta-analyses have also addressed the effect of traditional endurance exercise in children and adolescents, indicating decreased plasma triglycerides levels,[16] but no changes in systolic and diastolic blood pressure.[17] In meta-analyses including only children and adolescents with obesity and related comorbidities, significant positive effects of exercise were also reported for blood pressure,[18] markers of insulin sensitivity,[18, 19] and percentage body fat.[18]

Regarding the pediatric population, previous systematic reviews and meta-analyses have suggested that HIIT significantly improves cardiometabolic health and aerobic fitness, including in obese youth.[20-22] However, as recently pointed out by Lambrick et al., their results remain inconclusive and challenged by the rapid growing number of new studies in this area, underlying the need for new and more complete meta-analysis.[23] The primary aim of the present article was thus to determine from a systematic review and meta-analysis whether HIIT improves body composition and aerobic fitness, and decreases cardiovascular and metabolic risk parameters in overweight and obese children and adolescents.

EVIDENCE ACQUISITION

Database searching

The following electronic bibliographic databases were searched: MEDLINE, EMBASE, CINAHL, psycINFO, SPORTDiscus, and SocINDEX. All searches were conducted from November 2016 to February 2017. Keyword searches were performed for "children", "adolescent", "youth", "High Intensity", "intermittent training", "interval", "physical activity", "exercise", "sprint interval training", "continuous training", "overweight", "obese". Titles and abstracts of potentially relevant articles were screened and full-text copies were obtained for articles meeting initial screening criteria. Full-text articles were screened in duplicate for inclusion in the review. Any discrepancies were collectively discussed by the authors (JA and TD). All the selected references were then extracted to the Endnote software. The PRISMA guidelines were followed for the preparation of this paper.[24]

Study eligibility

Inclusion criteria.

To be included in the analysis, studies had to enroll overweight or obese children and adolescents ages 5 to 18 years. Medical conditions other than obesity and related disorders were excluded from the present study. The participants had to be non-smoking individuals, to be free of any medications affecting the control of energy balance or exercise contraindications. Importantly, studies were included if they implemented an exercise training program based on high-intensity interval exercises in at least one of the experimental groups. Published peer-reviewed studies, conference proceedings, theses, and dissertations were eligible.

Exclusion criteria.

Studies were excluded from further analysis if they did not implement a HIIT program for at least one of the experimental groups. When data were presented in the publication in a graphical form without mean or standard deviation precisions, the corresponding author of the work was contacted to obtain complementary data. If the corresponding author did not answer or declined the query, studies were excluded.

Data synthesis.

After a first selection based on the title of the papers, a second author independently assessed the papers' eligibility based on titles. Authors (JA, TD, JM, GB) had to code papers as "yes" or "no" or "maybe" for eligibility. Once this first round of selection was completed (based on title only), any disagreement was discussed and a common decision taken. The exact same procedure was followed a second time based on the abstract of the previously selected papers. Any disagreement regarding eligibility for inclusion was discussed and a consensus made among all co-authors. Computer files were developed containing the selected papers at each stage of the selection, and available to all the co-authors. By the end of the study selection process (as described above), all the references were classified in the EndNote reference management software. Then each of the two authors in charge of articles screening had to complete extraction files for the articles included. Any issue encountered by an author when extracting the data was discussed collectively and a consensus was adopted to harmonize the extraction process. For every article under consideration, an extraction sheet was completed by reviewers including sample size, the gender of the sample (or gender repartition), age, intervention characteristics and outcome measured. All the extraction sheets were then saved in a specific folder. The flow diagram presented in Fig 1 illustrates the selection/inclusion/exclusion process.

Synthesis of results.

Table 1 summarizes descriptive data about the included studies (Reference; Population; Design; Groups' characteristics; Intervention Description; Main Outcomes). Results from the included studies are reported in Table 2. Parameters reported are for each study: anthropometric characteristics and body composition, Aerobic fitness, other fitness parameters, metabolic profile and blood pressure, Physical activity and Energy Intake and Perceived exertion.

Risk of Bias in Individual studies.

The risk of bias was independently evaluated by two authors (TD and JA) using the Cochrane risk of bias tool [25]. The risk of bias was assessed for: selection bias; performance bias; detection bias; attrition bias; reporting bias. Any discrepancies in bias coding were resolved by a third reviewer (Table 3). Studies were not excluded on the basis of risk of bias.

Meta-analysis procedure

Upon data extraction, the data were compiled into software designed specifically for meta-analyses (Comprehensive Meta-Analysis, version 2; Biostat, Englewood, NJ). Included data were sample size, pre- and post-intervention body weight (BW), Body Mass Index (BMI), Body Fat percentage (BF%), Fat-Free Mass (FFM), VO_2max (ml.min^{-1} and ml.kg^{-1}.min^{-1}); Systolic and Diastolic Blood Pressure (SBP and SDP), Homeostatic Model Assessment of Insulin Resistance, Insulin plasma levels, Triglycerides, Total, High-Density Lipoprotein (HDL), and Low-Density Lipoprotein (LDL) Cholesterol. The mean standardized differences were calculated by the software to determine Cohen's d for each study and Hedge's g was used to account for potential bias to small sample sizes. Effect sizes (ES) were calculated by using a random-effects model that accounts for true variation in effects occurring from study to study, as well as random error within single study.

The effect sizes were interpreted according to Cohen such as <0.2 as trivial, 0.2–0.3 as small, 0.5 as moderate, and >0.8 as large.[26] Cochrane's Q and the I_2 index were used to calculate Heterogeneity with 25%, 50% and 75% respectively indicating low, moderate and high heterogeneity according to the I_2 analysis [27] and a Cochrane's Q value above the degree of freedom (df) to attest for a significant heterogeneity.[28] 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.[29] In absence of bias, studies should be distributed evenly around the mean ES because of random sampling error. Statistical significance was set at $p < 0.05$ in a Z-test analysis. The Z-tests were used to examine if ES were significantly different from zero.

EVIDENCE SYNTHESIS

The initial database search identified 236 references and 36 additional records were found using books of abstracts, conference proceedings, dissertation sources or personally submitted data, and finally, 253 references were identified after the suppression of duplicates. After review of titles and abstracts, 196 references were excluded, and 57 matched the inclusion criteria and were considered for analysis. Fifteen studies conducted with overweight/obese youth were included in the analysis (Figure 1).

Systematic approach in overweight and obese youth

Description of the included studies

Population characteristics

Of the 15 included studies, 10 enrolled obese subjects only,[30-39] Lau et al. included overweight subjects only,[40] and 3 studies enrolled overweight and obese subjects.[41-43] Ingul et al. included a control group of normal weight subjects that was compared to the intervention group at baseline, but not after the intervention.[44]

Three studies included boys only,[32, 36, 39] 3 studies enrolled girls only,[30, 34, 35] and the 9 remaining studies included both boys and girls.[31, 33, 37, 40, 41, 44 38, 42, 43] Two studies enrolled children under 12 years old,[31, 40] and the other studies enrolled children aged 12 years old and older.[30, 32-39, 41-44]

Design of the studies

Five studies were RCT,[30, 34, 35, 37, 40] six were randomized trial,[31-33, 36, 39] and 4 were observational studies.[38, 42-44] Two studies were conducted in a school setting,[35, 40] 7 studies were conducted in clinical setting.[30-32, 39, 41, 43, 44] The remaining studies did not describe the setting where they were conducted. [33, 34, 36-38, 42]

Four studies enrolled a single group that followed a HIIT program.[38, 42-44] Four studies compared a HIIT group to another group following a continuous moderate intensity exercise training program but did not have an untrained control group.[31-33, 36] Tjonna et al. compared a HIIT group with and continuous moderate intensity exercise training group, and a group following a multidisciplinary intervention.[41] Four studies compared a HIIT group to a continuous moderate intensity exercise training group, and to an untrained control group.[30, 34, 37, 40] Racil et al. compared a HIIT group with a HIIT + plyometric exercise group, and an untrained control group.[35] One study compared a HIIT group with a continuous high-intensity exercise training group, and a continuous low-intensity exercise training group.[39]

The duration of interventions of the included studies lasted from 3 weeks[39] to 6 months.[38, 42] Other studies lasted 4 weeks,[32, 43] 6 weeks,[33, 40] 8 weeks[37] and 3 months.[30, 34-36, 41, 44] Exercise training sessions were implemented twice a week in 5 studies,[31, 38, 41, 42, 44] 7 studies reported 3 sessions per week,[30, 33-36, 40, 43] and 4 sessions per week were implemented in one study.[32] Lazzer et al., reported a number of sessions of 28 ± 2 per subject during their 3-week program.[39] Kargarfard et al., reported 3 sessions per week in the HIIT group and 5 in the moderate intensity exercise training group.[37]

Main outcomes

All but one[37] of the included studies assessed body composition. Dual X-ray Absorptiometry was used in 2 studies,[41, 44] Bio-impedance analysis in 7 studies,[30-32, 34, 35, 39, 43] skinfold thickness measurement in 3 studies,[36, 40, 42] and air displacement plethysmography (Bod Pod) is one study.[33] Both BIA and skinfold thickness measurement were used in one study.[38]

All the included studies (15) assessed aerobic fitness. 11 out of 14 used an incremental maximal test performed in laboratory with measurement of maximal oxygen uptake (VO_2max).[30-32, 34-37, 39, 41, 43, 44] Within the remaining studies, the YoYo intermittent field test was used in one study,[40] the Astrand cycling test was used in one study,[33] a 6 minutes maximal running test was used in 2 studies.[38, 42]

Cardiometabolic risk blood markers were assessed in 8 studies,[30, 31, 34-38, 41] and systolic and diastolic blood pressure were assessed in 6 studies.[31, 34, 37, 38, 41, 44]

Energy intake was assessed in 4 studies using dietary recall.[31, 34, 35, 41] PA level was assessed in only one study using 7-day accelerometer records[41]. Basal metabolic rate and substrate oxidation were assessed in one study.[34]

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Main results

The main results of the 15 included studies are presented in Table 2.

Body Mass and Body Composition

Six studies did not report any change in body mass in response to HIIT,[32, 33, 37, 41, 43, 44] and 8 reported a significant decrease in BW.[30, 31, 34-36, 38-40] Racil et al. reported a significant decrease in BW following a moderate-intensity exercise training program, that was however significantly lower than following HIIT.[30] On the opposite, Lazzer et al. reported a significantly greater decrease in BW following low-intensity exercise training.[39]

Among the 12 studies that reported BMI results, 7 observed a significant decrease following HIIT.[30, 31, 34-36, 38, 41] Four of the studies also reported a significant decrease in BMI for the moderate–intensity exercise training group.[30, 31, 34, 36] The decrease in BMI was however significantly larger in the HIIT group compared to the moderate–intensity exercise training group in the study by Racil et al.[30] In their later study, Racil et al. observed decreased BMI in both HIIT and their comparison group (HIIT plus plyometric exercise) without any group effect.[35]

12 studies reported results of BF assessment. Three studies did not show any change in %BF.[32, 33, 43] Nine studies reported a significant decrease of %BF.[30, 34-36, 38-42] Racil et al. reported a significant decrease in %BF in a moderate-intensity exercise training group that was however significantly lower

than in the HIIT group.[30] Two studies reported similar BF decrease following HIIT and moderate-intensity exercise training.[34, 36] Lazzer et al. reported a higher body fat decrease in the low-intensity training group relative to the HIIT and high-intensity continuous training groups.[39]

7 out of the 8 studies reporting waist circumference (WC) measurements reported a significant decrease following HIIT,[30, 34-36, 38, 41, 44] and one study reported unchanged WC.[33] Five studies reported results for FFM, with three showing a significant increase after HIIT,[31, 35, 41] one study reporting unchanged FFM,[36] and one study reporting reduced FFM.[39]

Aerobic fitness

Three studies did not observe any change in aerobic fitness,[35, 37, 40] and one reported a decreased VO_{2peak}.[34] The 9 remaining studies reported increased aerobic fitness.[30-33, 36, 39, 41, 43, 44] Three studies also reported improved aerobic fitness following moderate-intensity exercise training.[30, 31, 36] When the two modalities of exercise training were compared, to the increase in aerobic fitness was significantly larger following HIIT relative to moderate-intensity exercise training in the study by Racil et al.[30] However, the same authors reported a decrease in VO_{2max} following HIIT or Moderate Intensity Intermittent Training (MIIT) in a following study.[34] Lazzer et al. reported improved VO_{2max} following HIIT and continuous high-intensity exercise training but no change following low-intensity exercise training.[39] Bluher et al. assessed aerobic fitness but did not report post-intervention results.[38] Substrate utilization was assessed in only one study, and fat and Carbohydrates (CHO) oxidation was unchanged in the low intensity training group, but fat oxidation significantly increased with HIIT high intensity continuous training.[39]

Muscle fitness

Only two studies reported the effect of HIIT on muscle fitness, indicating a significant improvement in lower limbs muscle strength.[35, 41] Lau et al. and Racil et al. also used an obstacle course to assess participants fitness and reported significantly improved performance, with reduced time needed to complete the course.[35, 40]

Physical Activity Level and Energy Intake

Four studies measured daily energy intake in response to the intervention, reporting either unchanged,[31, 34, 35] or decreased food intake.[41] The reduced energy intake observed by Tjonna et al. was attributed to a significant reduction in fat consumption while CHO and protein intake slightly increased.[41] Only Tjonna et al. assessed habitual PA level, using 7-day accelerometer records, but did not show any effect of the intervention on PA level.[41] Starkoff et al. reported unchanged PA enjoyment after HIIT.[33]

Main cardiometabolic risk parameters

Systolic Blood Pressure (SBP) was found reduced in 6 studies following.[31, 34, 37, 38, 41, 43] Three studies also reported decreased SBP following continuous submaximal exercise training.[34, 37, 41] Four studies reported reduced diastolic blood pressure (DBP),[34, 37, 38, 41] one study reported no change,[43] and one study reported decreased averaged blood pressure.[44]

Six out of the 15 studies included in the systematic review assessed insulin changes with exercise training.[30, 31, 34, 35, 38, 41] Five studies reported decreased insulin levels following HIIT or other types of exercise interventions.[30, 31, 34, 35, 41] However, only two of these studies reported significantly greater improvement in insulin sensitivity in the HIIT group compared to moderate intensity continuous exercise training.[30, 35] Bluher et al. who investigated the effect of HIIT but did not compare to another type of exercise training also reported decreased insulin levels.[38]

Plasma triglycerides (TG) levels were assessed in four studies.[30, 36, 38, 41] One study reported unchanged TG levels in the HIIT group, but a significant decrease in the control group[41] and Racil et al. found decreased plasma TG levels in both intervention groups, but a significantly greater decrease in the HIIT relative to the moderate intensity continuous training group.[30] Koubaa et al. reported decreased TG in the HIIT group only.[36] Bluher et al. found unchanged TG levels in the HIIT group.[38]

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Meta-Analysis

Body Mass. The effect sizes of individual studies ranged from -0.838 to 0.174 (n=11). There was a significant effect of HIIT, with decreased BM (-0.295 ; (95% CI = -0.525 to -0.066), p=0.012; Fig 2A), and no significant heterogeneity (I^2 = 0.000; Q = 8.73; d_f = 10, p=0.56).

Body Mass Index. The effect sizes of individual studies ranged from -0.673 to 0.083 (n =8). There was no significant effect of HIIT on BMI (-0.276 (95% CI = -0.565 to 0.012), p=0.061), and no significant heterogeneity (I^2 = 0.000; Q = 3.77; d_f = 7, p=0.81).

Fat-Free Mass. The effect sizes ranged from -0.588 to 0.437 (n = 5). There was no significant effect of HIIT on FFM (-0.085 (95% CI = -0.427 to 0.257), p=0.625), with no significant heterogeneity (I^2 = 10.19; Q = 4.45; d_f = 4, p=0.35).

Body Fat. The effect sizes of the individual studies ranged from -2.600 to 0.909 (n =9). There was a significant effect of HIIT on BF (-0.786 (95% CI = -1.452 to -0.120), p=0.021), but significant heterogeneity and high inconsistency of the effects (I^2 = 83.44; Q = 48.31; d_f = 8, p=0.000).

VO_2max $ml.kg^{-1}.min^{-1}$. The effect sizes of individual studies ranged from -0.115 to 2.854 (n =10). Results of the meta-analysis indicated a significant effect of HIIT on VO_{2max} (1.117 (95% CI = 0.528 to 1.706), p=0.000; Fig 2B). However, there was heterogeneity and high inconsistency in the effects of HIIT (I^2 = 78.31; Q = 41.48; d_f = 9, p=0.000).

Blood pressure, lipid profile and insulin resistance. Results are summarized in table 4. HIIT resulted in significant decrease in SBP,DBP, and HDL-C, triglycerides, HOMA-IR and insulin. However, there was significant heterogeneity and high inconsistency for most parameters. However, there was no significant effect of HIIT on total cholesterol and LDL-C.

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CONCLUSION

The purpose of the present systematic review and meta-analysis was to assess whether HIIT can reduce adiposity and cardiometabolic risk parameters in overweight or obese youth. The 15 included studied were designed to improve a combination of the following cardiometabolic risk parameters: aerobic fitness, body composition, blood pressure, indices of insulin sensitivity, and blood lipids.

Aerobic fitness

The meta-analysis indicates that HIIT can elicit significant improvement in aerobic fitness in overweight and obese youth. These results extend previous findings showing a significant positive effect of HIIT on cardiorespiratory fitness in the general adolescent population.[20] Most, but not all studies that assessed changes in aerobic fitness with HIIT reported improved VO_{2max}, or performances during various running or cycling tests to exhaustion in comparison with, baseline, untrained control groups, or groups following other types of exercise intervention. However, it remains unclear whether there is an advantage of HIIT over continuous moderate intensity exercise training from the studies that compared the two types of exercise training. Meta-analyses of adult studies comparing the effect of HIIT to that of endurance training showed that the benefits in terms of VO_{2max} improvement appear comparable.[12, 13, 15] It is to note that that one study showing significantly greater benefits of HIIT over moderate intensity continuous exercise training was conducted with girls only.[30]

Cardiometabolic risk factors – Body Mass and Adiposity

The meta-analyses showed that HIIT results in significantly decreases body mass and body fat but not fat-free mass, and BMI. Although there was a trend for a significant impact of HIIT on BMI, the finding is in contrast to the results of a previous meta-analysis in the general adolescent population that reported a significant decrease.[20] It is unclear why HIIT could be less effective in children and adolescents with excess body fat relative to the others, it can be hypothesized that it may be related to the intensity of exercise training. The meta-analysis in the general adolescent population[20] included a number of studies where subjects performed all out sprints or supramaximal intensity bouts of exercise, whereas all-out bouts of exercise were only performed in one study included in the present meta-analysis.[42] Regarding body composition, a previous review and meta-analysis of exercise training intervention that was not restricted to HIIT also showed a significant decrease in body fat in overweight children and adolescents,[45] indicating that exercise can be effective to improve body composition in this population. In addition, the effect of exercise training on body fat and BW loss was larger when studies with a low amount of exercise (3days/week) were excluded from the analysis, and there was a trend for larger effects with studies of longer durations.[45] The duration of HIIT intervention is in general shorter when compared to the studies included in the meta-analysis by Atlantis et al. where exercise training duration was 16 (±7) weeks.[45] Hence, HIIT may elicit faster changes in body composition than traditional endurance training. However, given the low number of studies comparing the two modalities of exercise training, caution is needed before considering HIIT as more effective than moderate intensity continuous exercise for improving body composition in overweight and obese youth.

Cardiometabolic risk parameters

HIIT appears effective to significantly decrease systolic and diastolic blood pressure in overweight and obese youth. This result provides additional support to previous meta-analyses in the general pediatric population for exercise training as a mean to decrease blood pressure.[17, 18] A strength of the present review and meta-analysis relative to the aforementioned studies is that it provides new results specific to the obese pediatric population and to HIIT. Regarding the other beneficial effects of HIIT on cardiometabolic risks markers, the effects observed should be considered cautiously as they are based on a limited number of studies. However, the meta-analysis results support a role for HIIT as an effective mean to decrease insulin resistance, and some, but not all, parameters of the blood lipid profile.

Limitations

The present systematic review and meta-analysis provide encouraging results regarding the efficacy of HIIT to improve aerobic fitness and reduce cardiometabolic risk parameters. However, even though low volume HIIT has attracted a lot of attention and research efforts over the last decade, the ability of people who are sedentary and physically inactive to engage in HIIT has been called into question.[6] This concern may also be relevant for children and adolescents whether they are obese or non-obese, as two studies indicated greater perceived exertion with HIIT than with lower intensity exercise in highly trained youth.[46, 47]

The short duration of HIIT training programs, the relatively low volume of weekly exercise training, and the low sample size of the populations studied are major limitations of the current HIIT studies. Indeed, no HIIT training programs lasted more than 12 weeks, and only one study reported outcomes at 12 months post-intervention.[41] In support of the need for longer interventions, a previous meta-analysis of the effect of exercise in overweight children and adolescents showed that the largest improvements in body composition are seen with longer duration of exercise training.[45] Differences for these parameters between studies may have contributed to the significant heterogeneity observed regarding the effects of HIIT on aerobic fitness and cardiometabolic risk factors.

Another limitation is that the metabolic effect of HIIT on parameters of energy metabolism, such as rate of substrate oxidation remains largely unexplored. It is already known from studies in overweight and obese youth that the maximal rate of fat oxidation can be increased with endurance exercise training, especially when performed at the intensity that elicits the maximal oxidation rate.[48-52] However, it remains unknown whether the muscle’s ability to oxidize fat is increased to the same extent in response to both HIIT and endurance training in children and adolescents.

To conclude, the present systematic review and meta-analysis suggest that HIIT is as effective as endurance training to improve aerobic capacity in overweight and obese youth. A second important result is that HIIT can significantly reduce blood pressure, reduce insulin resistance, triglycerides, and increase HDL-C. Current data are however insufficient to conclude that HIIT is more effective than moderate intensity continuous exercise training in this population. It should be acknowledged that other forms of exercise training combining HIIT and endurance exercise training may also have benefits for cardiometabolic health and physical fitness.

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Tables Legends

Table 1. Descriptive presentation of the selected studies in overweight and obese youth.

Table 2. Main results of the included studies involving overweight/obese youth [30-44].

Table 3. Study Risk of Bias [30-44].

Table 4. Results of Meta-analysis for metabolic profile

Figures Legends

Figure 1. Description of the screening, selection and inclusion process

Figure 2. (A) Effect size forest plot for body weight and (B) for VO2max (ml.kg^{-1}.min^{-1}) (mean ± 95% confidence intervals). [30-44].

Table 1. Descriptive presentation of the selected studies in overweight and obese youth [30-44].

Study	Population	Design	Groups	Intervention description	Main Outcomes
Tjonna et al. 2009[41] **(Norway)**	OW+OB adolescents n = 54 26 boys / 28 girls 14.0±0.3 years old	Randomized Trial	**HIIT** n =28 14 girls/14 boys **CG** n=26 14 girls/12 boys	3 months 2 sessions/week **HIIT** 10 min warm up 70% HRmax 4×4 min intervals at 90–95% of maximal HR / 3 min active recovery at 70% of HRmax (walking/running 'uphill' on a treadmill) 5 min cool-down **CG** multidisciplinary approach	Baseline, 3 months, and 12 months post-intervention. ***Aerobic fitness*** Maximal running GXT test (VO_{2max}) ***Body composition*** DXA ***Endothelial function*** ***Metabolic profile*** LDL-Cholesterol, adiponectin, NO_2-, insulin, HOMA ***Energy Intake*** Dietary food record ***Physical Activity Level*** 7-day accelerometer
Lau et al. 2014[40]	OW primary schools children	Randomized Crossover Trial	**HIIT** n=15	6 weeks 3 sessions/week	Baseline and post intervention

(Hong Kong)	n=48 36 boys 10.5±0.9 years old 12 girls 10.2±0.9 years old		**LIIT** n=21, **CG** n=12	Running interval: 15s running/15s passive recovery **HIIT** 12 interval at 120%MAS **LIIT** 16 intervals at 100% MAS **CG** No intervention	***Anthropometric characteristics*** ***Body composition*** Triceps and calf skinfolds ***Aerobic fitness*** Yo Yo Intermittent Endurance Test, level one (Castagna et al.,2006) ***Functional walking test*** Standardized Walking Obstacle Course (Held, Cott and Young, 2006)
Racil et al. 2013[30] **(Tunisia)**	OB girls n = 34 15.9±0.3 years old	Randomized Crossover Trial	**HIIT** n=11 **MIIT** n=11 **CG** n=12	12 weeks 3 times/week 30s intervals, with active recovery at 50% of MAS **HIIT** 100-110% of MAS **MIIT** 70-80% of MAS **CG** No intervention	Baseline and post intervention ***Aerobic fitness*** Incremental running test (VO_{2max} and MAS) ***Anthropometric characteristics*** ***Body composition*** BIA ***Blood sample*** Plasma lipids and adiponectine
Corte de Araujo et al. 2012[31]	OB	Randomized Trial	**HIIT**	12 weeks	Baseline and post intervention

(Brazil)	n = 30 9 boys / 21 girls 8-12 years old		n = 15 10 girls / 5 boys **CONT** n = 15 11 girls / 4 boys	2 sessions/week **HIIT** 3 (weeks 1-3) to 6 (weeks 10-12)* 60s walking/running bouts at 100% of the peak velocity 3-min active recovery period at 50% exercise velocity **CONT** 30min (weeks 1-3) to 60min (weeks 10-12) with 10min increment every 3 weeks, at 80% HRmax	***Aerobic fitness*** Maximal running GXT test (VO_{2max} and the associated peak velocity) ***Anthropometric measurements*** ***Body composition*** Bioelectrical impedance ***Systolic and diastolic blood pressure*** ***Metabolic profile*** Insulin, glucose, total cholesterol, HDL-, LDL- and VLDL-Cholesterol, Triglycerides, leptin, glycated hemoglobin
Murphy et al. 2014[32] **(USA)**	OB adolescents n=13 boys 12-18 years old	Randomized Trial	**HIIT** n=7 **CONT** n=6	4 weeks 3-4*50min/week **HIIT** 10*1min exercise bouts at 80 to 90% HRmax 2-min active recovery bouts at 60% HRmax **CONT** Continuous exercise at 65% of the estimated maximal aerobic capacity	Baseline and post intervention ***Aerobic fitness*** Maximal running GXT Bruce test (VO_{2max}) ***Body composition*** Bio-impedance ***Anthropometric measurements***

***Ingul et al., 2010*[44]** **(Norway)**	Adolescents n=20 10 obese – 14.8±1.2 yo 10 lean – 14.9±1.3 yo	Observational Only the obese sample trained	**HIIT** n = 10 obese	**HIIT** 13 weeks 2sessions/week 4*4min at 90%HRmax for 40 min	Baseline and post intervention ***Aerobic fitness*** Maximal treadmill graded test with indirect calorimeter ***Anthropometric measurements*** ***Body composition*** DXA ***Blood pressure***
***Racil et al., 2015*[34]** **(Tunisia)**	Obese adolescents n = 68 16.6 ± 1.3 yo females	Randomized controlled trial	**HIIT** n = 23 **HIIT + plyometric** n = 26 **CG** n = 19	12 weeks 3 times/week **HIIT** 2 blocks of 6 or 8 x 60 sec run 100% VO_{2peak} / 30 sec active recovery (50%VO_{2peak}) 4 min passive rest between blocks **HIIT + plyometric** Same as HIIT only preceded by 2 blocks of 3 plyometric exercises **CG** No intervention	Baseline and post intervention ***Aerobic fitness*** Maximal running test with indirect calorimetry ***Anthropometric measurements*** ***Body composition*** BIA ***Lower limb fitness*** Squat Jump and Counter Movement Jump ***Metabolic profile*** ***Energy Intake*** 4-day questionnaire

Koubaa et al., 2013)[36] **(Tunisia)**	Obese adolescents n =29 13 ± 0.8 yo boys	Randomized trial	**HIIT** n = 14 **CONT** n = 15	12 weeks 3 sessions/week **HIIT** X (number of repetitions not indicated)*2min run at 80%VO_{2max} with 1 min of rest. %VO_{2max} increased by 5% every 4 weeks. **CONT** 30 to 40 minutes at 60% (first 4 weeks) 65% (second 4 weeks) and 70% VO_{2max} (last 4 weeks).	Baseline and post intervention ***Aerobic fitness*** Maximal running test with indirect calorimetry ***Anthropometric measurements*** ***Body composition*** skinfolds ***Metabolic profile***
Starkoff et al., 2014[33] **(USA)**	Obese adolescents n =27 14.7±1.5 years old 17 girls 10 boys	Randomized trial	**HIIT** n = 14 **CONT** n = 13	6 weeks 3 sessions/week **HIIT** 10*2min cycling at 90-95% Maximal Heart Rate with 1 min active recovery (55% Maximal Heart Rate). **CONT** 30 60-70% Maximal Heart Rate.	Baseline and post intervention ***Aerobic fitness*** Astrand Cycle test ***Anthropometric measurements*** ***Body composition*** Air displacement plethysmography (Bod Pod) ***PA enjoyment*** Questionnaire

Herget et al., 2016[42] **(Germany)**	Overweight adolescents n =28 15.5±1.4 years old 15 girls 13 boys	Observational	**HIIT** n =28	6 months 2 sessions/week **HIIT** 10 min warm up 50-60% Max heart rate + Tabata interval training or Gibala interval training at 90-95% Max heart rate	Baseline and post intervention ***Aerobic fitness*** 6 min maximal running test ***Anthropometric measurements*** ***Body composition*** skinfolds ***PA level, sedentary behaviors, Quality of Life, social support, self-efficacy, internalization of stigmatization and outcome expectation*** Questionnaires
Lazzer et al., 2016 **(Italy)**[39]	Obese adolescents n =30 15-17 years old males	Randomized Trial	**HIIT** n=10 **LIT** n=11 **HIT** n=9	3 weeks 28 ± 2 sessions per adolescents **HIIT** 6*40 seconds walking at 100 VO_{2max} interspersed by 5 min walk at 40% VO_{2max} **LIT** Walking at 40%VO_{2max} for a mean duration of 45±6 min **HIT** Walking at 70%VO_{2max} for a mean duration of 31±4 min	Baseline and post intervention ***Aerobic fitness*** Maximal treadmill graded test with indirect calorimeter ***Anthropometric measurements*** ***Body composition*** BIA ***Basal metabolic rate*** Calorimeter ***Substrate oxidation*** Treadmill graded test with indirect calorimeter

Lee et al., 2016[43] **(USA)**	Overweight/Obese adolescents n =12 14.9 ± 1.5 years old	Observational	**HIIT** n = 12	4 weeks 3 sessions/week **HIIT** 10*10 seconds of cycling at 80-90% Max heart rate interspersed with 90 active recovery at 40-50% Max heart rate.	Baseline and post intervention ***Aerobic fitness*** Maximal cycling graded test with indirect calorimeter ***Anthropometric measurements*** ***Body composition*** BIA ***PA enjoyment*** Questionnaire
Racil et al., 2016[35] **(Tunisia)**	Obese adolescents n =47 14.2 ± 1.2 years old females	Randomized controlled trial	**HIIT** n = 17 **MIIT** n = 16 **CG** n = 14	12 weeks 3 times/week **HIIT** 4 min of 15 s at 100% MAS/15 s at 50% MAS (week 1 to 4) 6 min of 15 s at 100% MAS/15 s at 50% MAS (week 5 to 8) 8 min of 15 s at 100% MAS/15 s at 50% MAS (week 9 to 12) **MIIT** 4 min of 15 s at 80% MAS/15 s at 50% MAS (week 1 to 4)	Baseline and post intervention ***Aerobic fitness*** Incremental running test VO_{2max} and MAS ***Anthropometric measurements*** ***Body composition*** BIA ***Metabolic profile and blood pressure*** **Energy Intake** 4-day questionnaire

				6 min of 15 s at 80% MAS/15 s at 50% MAS (week 5 to 8) 8 min of 15 s at 80% MAS/15 s at 50% MAS (week 9 to 12) **CG** No intervention	
Kargarfard et al., 2016[37] **(Iran)**	Obese adolescents n =30 obese 12.3 ± 1.3 years old n = 30 lean 12.2 ± 1.5 years old	Randomized controlled trail	**HIIT** n = 10 obese and 10 lean **CONT** n = 10 obese and 10 lean **CG** n = 10 obese and 10 lean	8 weeks **HIIT** 3 sessions per week 4 min at 60-70% reserve heart rate followed by 2 minutes at 40-50% until exhaustion. 5% increase of the intensity every 2 weeks. **CONT** 5 sessions per week 50-60 run at 60-70% Heart Rate reserve at the beginning to progressively reach 80-95% by the end (5%every two weeks) **CG** n = 10 obese and 10 lean	Baseline and post intervention ***Aerobic fitness*** Maximal cycling graded test with indirect calorimeter ***Anthropometric measurements*** ***Metabolic profile and blood pressure***

Bluher et al., 2017[38] **(Germany)**	Obese adolescents n =20 15.5 ± 1.4 years old Boys and girls	Observational	**HIIT** n = 20	6 months 2 sessions per week **HIIT** 10 min warm up 50-60% HRmax 80-95% HRmax running bouts with 50-60%HRmax active intervals (duration of intervals not indicated)	Baseline and post intervention ***Aerobic fitness*** 6-minute maximal running test ***Anthropometric measurements*** ***Body composition*** BIA + skinfolds ***Metabolic profile and blood pressure***

NW: Normal Weight; OW: Overweight; OB: Obese; HIIT: High Intensity Intermittent Training; MIIT: Moderate Intensity Intermittent Training; LIIT: Low Intensity Intermittent Training; LIT: Low Intensity Training; HIT: High Intensity Training; CONT: Continous training; CG: Control Group; SSG: Small Side Game; SIG: Short Intermittent Group; LIG: Long Intermittent Group; HRmax: maximal Heart Rate; VO_{2max}: Maximal oxygen uptake; AT: Anaerobic Threshold; MAS: Maximal Aerobic Speed, the lowest speed associated with VO_{2peak}; rpm: rotations per minute; GXT: graded incremental exercise test; BMI: Body Mass Index, $kg.m^{-2}$; DXA: Dual-energy X-ray absorptiometry; HOMA: Homeostasis Model Assessment; HDL (High Density Lipoprotein); LDL (Low Density Lipoprotein); VLDL (Very Low Density Lipoprotein) ; VT1: Ventilatory Threshold 1; VT2: Ventilatory Threshold 2; SJ: Squat Jump; CMJ: Counter Movement Jump; DJ: Drop Jump; *nr:* not reported; 30-15IFT: 30-15 seconds intermittent fitness test.

Table 2. Main results of the included studies involving overweight/obese youth [30-44].

Study	**Anthropometric characteristics Body composition**	**Aerobic fitness**	**Other fitness parameters**	**Metabolic profile Blood pressure**	**Physical activity level Energy Intake Perceived exertion**
Tjonna et al. 2009[41] (Norway)	Body mass unchanged / ↓BMI in HIIT / ↓WC in HIIT / ↓%BF in HIIT / ↑FFM in HIIT	↑ VO_2ml.min^{-1}.kg^{-1} in HIIT ↑ VO_2ml.min^{-1}.kg^{-1} FFM in HIIT	↑Max leg strength in HIIT	↓SBP in both groups / ↓DBP in HIIT ↓ insulin, glucose, HbA_{1c} in both groups ↓ TG in CG only	PAL: No group and intervention effect ↓EI in HIIT: ↑prot / ↓fat / ↑CHO
Lau et al. 2014[40] (Hong Kong)	↑Body mass, BMI, Σskinfold in CG ↓Body mass in HIIT and LIIT ↓Σskinfold in HIIT	MAS unchanged	↓Time obstacle course in HIIT Steps number obstacle course: ↓HIIT; ↑in CG YYIET distance: ↑ in HIIT		
Racil et al. 2013[30] (Tunisia)	↓%BFin HIIT and MIIT (HIIT>MIIT) ↓Body mass in HIIT and MIIT ↓zBMI in HIIT and MIIT (HIIT>MIIT) ↓WC HIIT	↑MAS in HIIT and MIIT (HIIT>MIIT) ↑VO_2peak inHIIT and MIIT		↓ TC, TG in HIIT ↓ Adiponectin, insulin, LDL-C, HOMA in HIIT and MIIT (HIIT>MIIT) ↑ HDL-C HIIT and MIIT	
Corte de Araujo et al. 2012[31] (Brazil)	↓ Body mass in HIIT ↓ BMI in both groups	↑absolute and relative VO_2peak in HIIT and CONT ↑peak velocity and exercise time during CRF test in HIIT and CONT ↑ΔHRR1 in HIIT ↑ΔHRR2 in both groups		↓ insulin and HOMA in both groups ↓ SBP in HIIT	EI unchanged
Murphy et al. 2014[32] (USA)	%BF and Body mass unchanged	↑ VO_2max ml.min^{-1}.kg^{-1} CONT ↑ VO_2max ml.min^{-1}.kg^{-1} FFM HIIT			
Ingul et al., 2010[44] ***(Norway)***	BM and BMI unchanged ↓WC	↑VO2max (absolute and relative) ↓HRrest		↓ Blood pressure	
Racil et al., 2015[34] **(Tunisia)**	BM ↓ HIIT and HIIT+P BMI ↓ HIIT and HIIT+P BF% ↓ HIIT and HIIT+P LBM ↑ HIIT WC ↓ HIIT and HIIT+P	VO2peak unchanged VO2peak HIIT and HIIT+P > CG	SJ ↑ HIIT and HIIT+P SJ HIIT > HIIT+P CMJ ↑ HIIT and HIIT+P CMJ HIIT > HIIT+P	Insulin ↓ HIIT and HIIT+P Glucose ↓ HIIT and HIIT+P HOMA ↓ HIIT and HIIT+P	

Koubaa et al., 2013)[36] **(Tunisia)**	BM ↓ HIIT and CONT BMI ↓ HIIT and CONT BF% ↓ HIIT and CONT FFM ↔ HIIT and CONT WC ↓ HIIT and CONT	↑ VO_2max ml.min^{-1}.kg^{-1} HIIT and CONT ↑ MAS HIIT and CONT ↓ Resting HR in HIIT and CONT	↓ TG in HIIT only ↑ HDL-C HIIT and CONT ↓ LDL-C HIIT and CONT	
Starkoff et al., 2014[33] **(USA)**	BM, %BF, WC, BMI ↔ in HIIT and CONT	↑ VO_2max ml.min^{-1}.kg^{-1} HIIT only		Physical activity enjoyment unchanged in both groups
Herget et al., 2016[42] **(Germany)**	BMI, WC ↔ HIIT BF% ↓ HIIT			
Lazzer et al., 2016[39] **(Italy)**	↓BM HIIT / HIT /LIT (LIT>HIIT and HIT) ↓ FFM and %BF HIIT / HIT /LIT (LIT>HIIT and HIT)	BMR ↔ all groups ↔ VO2 LIT ↑VO2 HIIT and HIT ↔ EE, CHO oxidation and Fat oxidation in LIT ↑ BMR and fat oxidation between 50% and 70% VO2peak in HIIT and HIT ↔ EE, CHO oxidation in HIIT and HIT		
Lee et al., 2016[43] **(USA)**	↔ BM and BF% HIIT	↑ VO_2max ml.min^{-1}.kg^{-1} HIIT ↑ VO_2max test duration HIIT	↓ SBP HIIT ↔ DBP HIIT	
Racil et al., 2016[35] **(Tunisia)**	↓ BM, %BF, BMI in HIIT and MIIT (↔CG) ↓WC HIIT ↔WC MIIT and CG	↔ Max Heart rate all groups ↓ resting HR HIIT and MIIT (↔CG) ↔ RER all groups ↓ VO2peak HIIT and MIIT (↔CG)	↓ SBP and DBP HIIT and MIIT (↔CG) ↓ glucose, insulin, HOMA-IR, leptin HIIT and MIIT (↔CG)	↔ EI all groups ↓ RPE index HIIT and MIIT (↔CG)
Kargarfard et al., 2016[37] **(Iran)**	↔ BM, BMI HIIT CONT	↔ VO2max HIIT CONT	↓ SBP and DBP HIIT and CONT ↔ DBP HIIT and CONT	
Bluher et al., 2017[38]	↓ BM, %BF, BMI, WC	Not reported	↓ SBP and DBP ↓ insulin, HOMAIR ↔ TG, HDLC, LDLC	

↑: increase, ↓: decrease; VO_2: maximal oxygen uptake*;* HIIT: High Intensity Intermittent Training; MIIT: Moderate Intensity Intermittent Training; LIIT: Low Intensity Intermittent Training; CONT: Continuous training; CG: Control Group; LIT: Low Intensity Training; HIT: High Intensity Training; SSG: Small Side Game; AT: Anaerobic Threshold; VT: Ventilatory Threshold; BMI: Body Mass Index (kg.m^{-2}); %BF: Percentage of Body Fat; WC: Waist Circumference; FFM: Fat-Free Mass; MAS: Maximal Aerobic Speed, the lowest speed associated with VO_{2peak}; HRmax: maximal Heart Rate; CMJ: Counter Movement Jump; rpm: rotations per minute during cycling exercise*;* HDL: High Density Lipoprotein, LDL: Low Density Lipoprotein, VLDL: Very Low Density Lipoprotein, TG: Triglycerides*;* TC:: Total Cholesterol, Prot:

Protein, PA: Physical Activity, EI: Energy Intake, PAL: Physical Activity Level; SBP: Systolic Blood Pressure, DBP: Diastolic Blood Pressure, HOMA: Homeostatic Model Assessment, CRF: Cardio-Respiratory Fitness; RPE: Rating of Perceived Exertion, SIG: Short Intermittent Group, LIG: Long Intermittent Group

Table 3. Study Risk of Bias [30-44].

Study	Random Sequence Generation (Selection bias)	Allocation concealment (selection bias)	Blinding participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Tjonna et al., 2009[41]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Lau et al., 2014[40]	High risk	NR	Low risk	Low risk	NR	Low risk
Racil et al., 2013[30]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Corte de Araujo et al., 2012[31]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Murphy et al., 2014[32]	High risk	NR	Low risk	Low risk	NR	Low risk
Ingul et al., 2010[44]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Racil et al., 2015[34]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Koubaa et al., 2013[36]	Low risk	NR	Low risk	Low risk	NR	Low risk
Starkoff et al., 2014[33]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Herget et al., 2016[42]	High risk	NR	Low risk	Low risk	Low risk	Low risk
Lazzer et al., 2016[39]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Lee et al., 2016[43]	High risk	NR	Low risk	Low risk	Low risk	Low risk
Racil et al., 2016[35]	Low risk	NR	Low risk	Low risk	Low risk	Low risk
Kargarfard et al., 2016[37]	Low risk	NR	Low risk	Low risk	NR	Low risk
Bluher et al., 2017[38]	High risk	NR	Low risk	Low risk	NR	Low risk

NR : Not-reported

Table 4. Results of Meta-analysis for metabolic profile

	n	Effect size	Mean effect	95% CI	p	Heterogenity			
						I^2	Q	df	p
Total Cholesterol (mg/dl)	4	-0.857 to 0.032	-0.258	-0.646 to 0.130	0.193	12.401	3.425	3	0.331
LDL-C (mg/dl)	4	-0.856 to 0.074	-0.274	-0.636 to 0.087	0.137	0.000	2.736	3	0.434
HDL-C (mg/dl)	5	-0.026 to 0.848	0.423	0.093 to 0.753	0.012	0.000	3.300	4	0.509
Triglycerides (mg/dl)	5	-1.811 to -0.029	-0.550	-1.066 to -0.033	0.037	56.757	9.250	4	0.055
Insulin (mUI/l)	6	-3.880 to -0.242	-0.860	-3.024 to -0.696	0.002	91.241	57.082	5	0.000
HOMA-IR	5	-2.456 to -0.206	-1.589	-2.528 to -0.650	0.001	85.764	28.098	4	0.000
DBP (mmHg)	8	-3.177 to 0.402	-0.966	-1.628 to -0.304	0.004	80.868	36.588	7	0.000
SBP (mmHg)	8	-2.826 to -0.527	-1.026	-1.370 to -0.683	0.000	30.567	10.082	7	0.184

LDL-C : Low Density Lipoprotein Cholesterol ; HDL-C: High Density Lipoprotein Cholesterol; HOMA-IR: Homeostatic Model Assessment Insulin Resistance; DBP: Diastolic Blood Pressure; SBP: Systolic Blood Pressure.

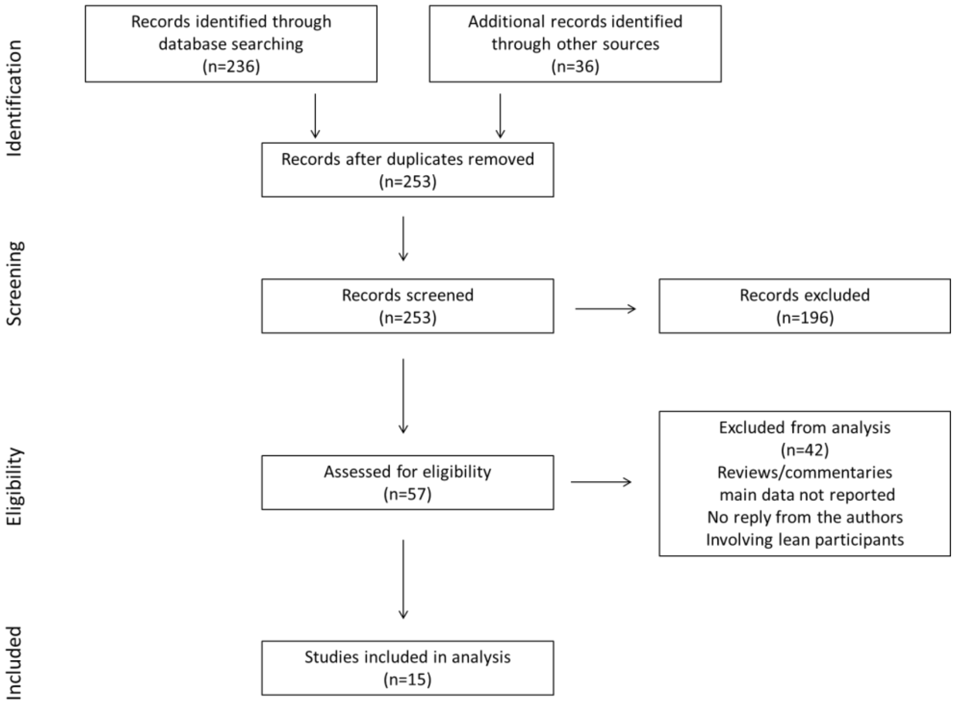

Figure 1. Description of the screening, selection and inclusion process

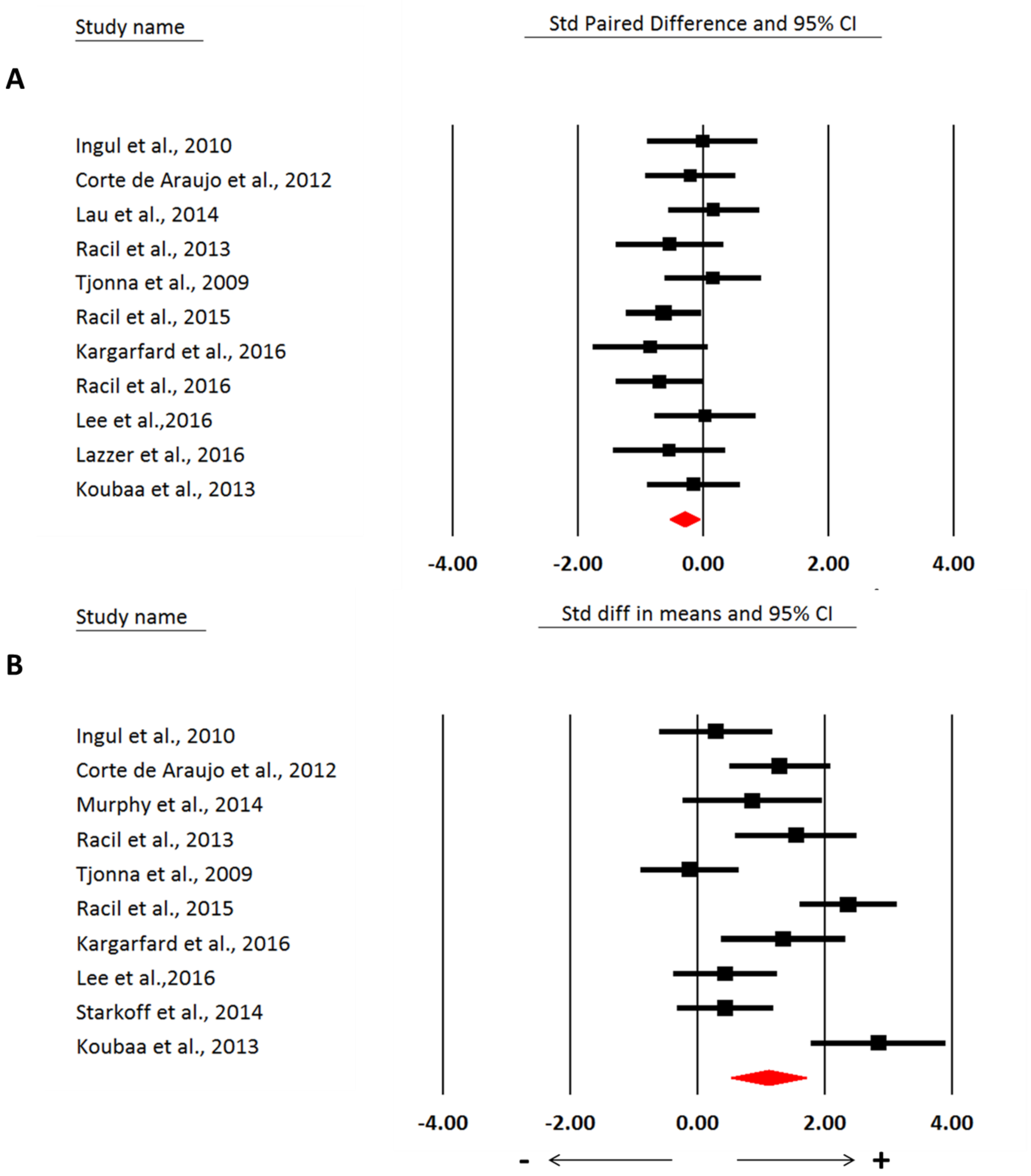

Figure 2. (A) Effect size forest plot for body weight and (B) for VO2max (ml.kg^{-1}.min^{-1}) (mean ± 95% confidence intervals). [30-44]