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High intensity interval training for improving health-related fitness in adolescents: A systematic review and meta-analysis

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ABSTRACT

Background

High Intensity Interval Training (HIIT) may be a feasible and efficacious strategy for improving health-related fitness in young people. The objective of this systematic review and meta-analysis was to evaluate the utility of HIIT to improve health-related fitness in adolescents and to identify potential moderators of training effects.

Methods

Studies were considered eligible if they: (1) examined adolescents (13-18 years), (2) examined health-related fitness outcomes, (3) involved an intervention of ≥4 weeks in duration, (4) included a control or moderate intensity comparison group, and, (5) prescribed high intensity activity for the HIIT condition. Meta-analyses were conducted to determine the effect of HIIT on health-related fitness components using Comprehensive Meta-analysis software and potential moderators were explored (i.e., study duration, risk of bias and type of comparison group).

Results

The effects of HIIT on cardiorespiratory fitness and body composition were large and medium, respectively. Study duration was a moderator for the effect of HIIT on body fat percentage. Intervention effects for waist circumference and muscular fitness were not statistically significant.

Conclusions

HIIT is a feasible and time efficient approach for improving cardiorespiratory fitness and body composition in adolescent populations.

INTRODUCTION

The health benefits of physical activity are extensive [1, 2]. Current physical activity guidelines recommend that adolescents (13-17 years) partake in 60 minutes of moderate-to-vigorous physical activity each day, in addition to participating in muscle and bone strengthening activities at least three times per week [3]. While the benefits of physical activity are well established [2, 4], physical *in*activity during adolescence is widespread [5, 6]. Data collected from more than 100 countries report 80% of adolescents (13–15 years) do not achieve the recommended levels of physical activity [6]. Furthermore, physical activity participation declines precipitously during adolescence [7]. A systematic review examining changes in physical activity of adolescents in 26 studies, reported an average decline of 7% per year throughout adolescence [8]. Adolescent fitness levels also appear to be declining [9], where aerobic fitness of Australian youth declined on average by 0.24% each year since the 1960's [9]. These trends are concerning given behaviours established during this period are likely to continue into adulthood [10].

There is clearly a need to develop strategies to engage adolescents in sufficient physical activity to maintain and improve their health-related fitness. High intensity interval training (HIIT) has emerged as a feasible and efficacious strategy for increasing health-related fitness in adult populations [11]. HIIT generally consists of short, yet intense bouts of exercise interspersed by brief rest periods. The main appeal of HIIT is that this type of training can be completed in a short period of time (compared to traditional aerobic training), it requires no or minimal equipment, and physical adaptations are comparable to those resulting from endurance training [12].

A growing body of literature supports the efficacy of HIIT for promoting favourable health-related outcomes in adult populations. Although two systematic reviews and meta-analyses examining the effects of HIIT on health outcomes with adult populations have concluded that it is both safe and efficacious [13, 14] , it is unclear whether this approach has utility for young people. Given that lack of time [15] and access to facilities [14] are commonly reported barriers to participation in physical activity, HIIT may also be a feasible approach for adolescents.

A recent narrative review of 11 studies, summarised the impact of HIIT on adolescents' metabolic health (e.g., glycaemia and insulinaemia, blood lipids, body composition, aerobic fitness and inflammation) [16]. HIIT produced equal or better cardio metabolic gains in a shorter time period in comparison to steady state exercise. However, the authors did not conduct meta-analyses to determine the pooled effect sizes, explore potential moderators of training effects or report the HIIT effects for muscular fitness. Therefore, our aim was to evaluate the efficacy of HIIT for improving health-related fitness (i.e., cardiorespiratory fitness, muscular fitness, body composition and flexibility) in adolescent populations and to identify potential moderators of intervention effects. This review extends the existing literature by investigating interventions of ≥4 weeks duration for general and elite/trained adolescent populations, which have utilised a control/comparison group and have monitored exercise intensity (e.g., use of heart rate monitors).

METHODS

Search strategy

A structured electronic search of all publication years (through April 2014) using Academic Search Complete, PubMed, EMBASE, CINAHL Complete, MEDLINE Complete, SPORTDiscus with Full Text, Psychology and Behavioral Sciences Collection, and SCOPUS was conducted. The following search strings were used: (high intensity interval training OR high intensity intermittent training OR high intensity interval exercise OR high intensity circuit training OR high intensity training OR high intensity exercise OR high intensity aerobic interval training OR aerobic interval training OR aerobic exercise training) AND (adolescen* OR teen* OR youth OR young people). These strings were further limited to peer-reviewed publications written in English. First, title and abstracts of articles identified in the search process were assessed for suitability. Second, full-text articles were retrieved and assessed for inclusion. Finally, reference lists from retrieved full-text articles were searched.

Study selection criteria

Studies were considered eligible if they: (1) examined adolescents (13-18 years); (2) examined health-related fitness outcomes; (3) involved an intervention of ≥4 weeks in duration; (4) included a control or moderate intensity comparison group; and, (5) prescribed high intensity activity (e.g., 85–95% peak heart rate or 80–100% peak work rate), as defined by Weston and colleagues in a recent review [17]. Conference abstracts, dissertations, theses and articles published in non-peer-reviewed journals were not included for review.

Data extraction

Key study characteristics were extracted including: the country of origin, size and source of study population, study design, age, population group, intervention setting, study duration, HIIT dose, fitness outcomes, length of follow-up, retention rate and study results.

Risk of bias

Two reviewers (SAC and NE) independently assessed the risk of bias of studies that met the inclusion criteria. Scoring discrepancies were resolved via consensus and inter-rater reliability was calculated using percentage agreement. Risk of bias for the 20 studies was assessed using an eight item checklist adapted from the PRISMA statement [18]. A risk of bias score was awarded to each study based on an 8-point scale coded as “explicitly described and present”(✓), “absent”(x) or “unclear or inadequately described”(?), for each of the following criteria: (a) Eligibility criteria were specified; (b) Participants were randomly allocated to groups; (c) The groups were similar at baseline regarding the primary outcome(s); (d) There was blinding of all assessors who measured the primary outcome(s); (e) Data for primary outcome(s) were analysed by ‘intention to treat’; (f) Dropout for primary outcome(s) described, with <20% dropout of participants; (g) Sample size calculations were conducted and the study was adequately powered to detect changes in the primary outcome(s); and, (h) Summary results for each group plus estimated effect size (difference between groups) and its precision (e.g., 95% CI) were reported. Criteria were added to create an overall risk of bias score: low risk of bias studies (8-7), moderate risk of bias (6-4) and high risk of bias (3-0).

Meta-analysis

Meta-analyses were conducted to determine the effect of HIIT on health-related fitness components, in comparison to non-training control groups or moderate intensity comparison groups. For studies that included both non-training control groups and moderate intensity comparison groups, only the control group data were included in the meta-analyses. Post-test mean values or change scores and their standard deviations were used in the meta-analyses, which were conducted using Comprehensive Meta-Analysis software, Version 2 for Windows (Biostat company, Englewood NJ, USA) [19]. Fixed and random effects meta-analysis results are reported in the figures (mixed effects resulted reported in the text). Heterogeneity was determined by Cochrane’s Q statistic and I^2 values, whereby values of <25, 50, and 75 were considered to indicate low, moderate and high heterogeneity, respectively [20]. Publication bias was analysed using Rosenthal’s *classic fail-safe N* [21], which provides an indication of the number of studies needed with a mean effect of zero before the overall effect would no longer be statistically significant.

Separate meta-analyses were carried out for: i) cardiorespiratory fitness (estimated or actual maximal oxygen uptake); ii) muscular fitness (jump height); and iii) body composition (BMI, body fat % and waist circumference). The weighted unstandardised average effect sizes, their 95% confidence intervals and *p*-values are reported. Standardised effect sizes (Cohen's *d*) and 95% confidence intervals are also reported. Summary effect sizes were considered statistically significant at $p < .05$. Subgroup moderator analyses were conducted to determine if HIIT effects differed according to duration of study (i.e., < 8 weeks versus ≥ 8 weeks), type of comparison group (i.e., moderate intensity training group or non-training control group) and risk of bias (i.e., low, moderate or high). Moderator effects were considered significant at $p < .1$.

RESULTS

The search yielded 1168 studies (see Figure 1). Once duplicates were removed, and abstracts (n=630) and full papers (n=124) were screened, a total of 20 studies were included in the review (see Table 1). Descriptive characteristics and fitness outcomes of the 20 studies are outlined in Tables 1 and 2. Briefly, more than half of included studies employed a randomised control trial study design (13 of 20, 65%). Samples sizes ranged from 10 [22] to 503 [23]; intervention length ranged from 4 weeks [22, 24, 25] to 8 months [26] in duration. Studies were conducted in Scotland [27-30], France [23, 31, 32], Germany [22, 33, 34], Norway [35-37], Switzerland [24, 25], Tunisia [9, 38], Belgium [39], Brazil [40], and the USA [26]. Studies assessed a range of adolescent population groups, including school students [23, 27-30], obese adolescents [9, 26, 35, 36, 38, 40], soccer players [24, 25, 34], adolescents with intellectual disabilities [39] and a range of elite/professional adolescent athletes including handball players [32, 41], footballers [33], skiers [37] and swimmers [22]. Studies were conducted in a range of settings, including schools [23, 27-30, 38, 39], sporting clubs [22, 24, 25, 33, 34, 37], training centres [31, 32], hospitals [35, 36], a community-based facility [40] and a research institute [26].

Sprint running [9, 23-25, 27-34, 38] was utilised in the majority of studies (13/20; 65%). Additional training methods included: treadmill walking/running with an incline [35, 36, 40], roller ski staking [37], and sprint cycling [39]. Only one study employed a range of training modalities [26], including machine-based exercise (e.g., treadmills, cycles, rowers, and steppers), aerobics, basketball, badminton, kickball, and aerobic slide.

Table 1: Study Characteristics

Study	Age / Population Group / Setting	Intervention duration/ Frequency / HIIT approach	HIIT vs. Comparison Group (Work:Rest)	Retention rate / Follow up
Banquet 2001 **N:** 503 **Country:** France **Study design:** Non-RCT	11 to 16 Adolescents School	10 weeks 1 hour/week of HIIT; 2 hours of regular PE Running	HIIT: 100–120 % maximum aerobic speed (10sec:10sec) Comparison: 3 hours of regular PE per week	NS Post-intervention
Boer 2014 **N:** 54 **Country:** Belgium **Study design:** RCT	17(3.0) Adolescents with intellectual disability School	15 weeks 2 sessions/week Cycling: Sprint interval training	HIIT: Week 1-7: 10 sprint bouts at a resistance matching with the ventilatory threshold (15sec:45sec). Weeks 8-15: 10 sprint bouts 110% ventilatory threshold (15sec:45sec). Comparison: three blocks of 10 min continuous training and a non-exercising control group	85% Post-intervention
Buchan 2011a **N:** 57 **Country:** Scotland **Study design:** RCT	16.4(0.7) Adolescents School	7 weeks 3 sessions/week Maximal sprint running	HIIT: four to six repeats of maximal sprint running within a 20 m area (30sec:30sec) Control: maintain usual behaviour	NS Post-intervention
Buchan 2011b **N:** 57 **Country:** Scotland **Study design:** RCT	16.4(0.7) Adolescents School	7 weeks 3 sessions/week Sprints	HIIT: four to six repeats of maximal sprint running within a 20 m area (30sec:30sec) Comparison: moderate intensity (70% VO2max) running for a period of 20 min and a control group (maintain usual behaviour).	96% Post-intervention
Buchan 2012 **N:** 41 **Country:** Scotland **Study design:** RCT	15-17 Adolescents School	7 weeks 3 sessions/week Sprints	HIIT: four to six repeats maximal effort sprint within a 20 m distance (30sec:30sec) Control group: maintain usual behaviour	NS Post-intervention
Buchan 2013 **N:** 89 **Country:** Scotland **Study design:** RCT	16.7(0.6) Adolescent School	7 weeks 3 sessions/week Maximal sprint running	HIIT: four to six repeats of maximal sprint running within a 20 m (20-30sec:20-30sec) Control: maintain usual behaviour	NS Post-intervention
Buchheit 2008 **N:** 15 **Country:** France **Study design:** Experimental	15.6(0.8) Trained male handballers Training facility	9 weeks 2 sessions/week Sprints	HIIT: sprints at 95% of the speed reached at the end of the 30–15 intermittent fitness test (15-20sec:15-20sec) Comparison: Repeated Sprints all-out 6-s shuttle sprints; 14–20 s of recovery	88% 1 week post intervention
Buchheit 2009 **N:** 32 **Country:** France **Study design:** Experimental	15.5(0.9) Young elite handball players Regional training	10 weeks 2 sessions/week Sprints	HIIT: 12–24 sprints at 95% of the speed reached at the end of the 30–15 Intermittent Fitness Test (15sec:15sec) Comparison: Handball Training, small-sided handball games	84% Within 2 weeks post intervention

	centre			
Farah 2014 **N:** 43 **Country:** Brazil **Study design:** RCT	13-18 Obese adolescents Community-based facility	6 months 3 sessions/week Treadmill	HIIT: exercised at an intensity corresponding to the ventilatory threshold (exercise sessions were isocaloric, with energy expenditure set at 350 kcal). Comparison: Low intensity training, exercised at a speed 20% below ventilatory threshold	44% Post-intervention
Faude 2008 **N:** 10 **Country:** Germany **Study design:** Randomised cross over design	16.6(1.4) Competitive swimmers Sports club	4 weeks 6 days/week Swimming	HIIT: 5 × 400m at 101% individual aerobic threshold, rest 90 sec Comparison: 20 × 100m at 97% individual aerobic threshold, rest 10 sec	NS Post-intervention
Faude 2013 **N:** 20 **Country:** Germany **Study design:** Cross-over trial	15.9(0.8) High level youth footballers Football club	5.5 weeks 2-3 sessions/week Running	HIIT: HIIT consisted of two sets of 12-15 near-maximum runs of 15, 20 or 30 sec duration. (1:1) Comparison: High-volume continuous endurance running consisted of continuous or fartlek runs of 30 to 60 min	48% Post-intervention
Gutin 2002 **N:** 80 **Country:** USA **Study design:** RCT	13-16 Obese adolescents Research institute	8 months Offered 5 days/week Variety of activities	HIIT: 75–80% of peak VO2 Comparison: 55–60% of peak VO2 (The number of minutes of exercise needed to expend 1045 kJ was estimated for each subject, therefore session time varied)	71% Post-intervention
Impellizzeri 2006 **N:** 40 **Country:** Switzerland **Study design:** RCT	17.2(0.8) Junior teams of professional soccer clubs, Football club	4 weeks 2 sessions/week running	HIIT: 4 bouts of 90–95% of maximum heart rate (4min:3min) Comparison: general training (small sided games)	73% measured after 4 weeks and after 8 weeks of training
Impellizzeri 2008 **N:** 26 **Country:** Switzerland **Study design:** RCT	17.8(0.6) Junior soccer players Football club	4 weeks Week 1: 2 sessions Weeks 2-4: 3 sessions Running	HIIT: 4 bouts of 90–95% of maximum heart rate (4min:3min) Comparison: completed normal training sessions, low-intensity technical and tactical training sessions	81% 1 week post intervention
Ingul 2010 **N:** 10 **Country:** Norway **Study design:** Experimental	14.8(1.2) Obese adolescents Referred from general practice	13 weeks 2 sessions/week Walking or running with elevation on a treadmill	HIIT: 4 bouts at 90% of maximal heart rate (4min:6min) Control: Non-active control	100% Post-intervention
Koubaa 2013 **N:** 29 **Country:** Tunisia **Study design:** RCT	13(0.8) Obese males NS	12 weeks 3 sessions/week Running	HIIT: exercise intensity was 80% of the VO2max, increased by 5% every four weeks (2min:1min) Comparison group: 30-40 minute continuous exercises a 60%-70 % of VO2max	100% Post-intervention

Racil 2013 **N:** 34 **Country:** Tunisia **Study design:** RCT	15.9(0.3) Obese females School	12 weeks 3 sessions/week Running	HIIT: 100 to 110 % of maximal aerobic speed (30sec:30sec) Comparison group: exercising at 70–80% of maximal aerobic speed and a non-exercising control group	94% Post-intervention
Sandbakk 2011 **N:** 15 **Country:** Norway **Study design:** Experimental	17.4(0.5) Elite cross country skiers Sporting club	8 weeks NS Roller ski skating	HIIT: long duration intervals (5–10 minutes), with an intensity of 85–92% of heart rate max Comparison: continued baseline training	100% Post-intervention
Sperlich 2011 **N:** 19 **Country:** Germany **Study design:** Experimental	13.5(0.4) Soccer players Sports club	5 weeks 3-4 sessions/week Running	HIIT: 90–95% of individual maximal heart rate, separated by periods of 1–3 minutes jogging at approximately 50–60% of maximal heart rate according to the training program Comparison: high volume training 60–75% of maximal heart rate	94% Post-intervention
Tjonna 2009 **N:** 54 **Country:** Norway **Study design:** RCT	14(0.3) Overweight adolescents Hospital	3 months 2 sessions/week Walking/running 'uphill' on a treadmill	HIIT: 4 intervals at 90% of maximal heart rate, separated by 3 min at 70% (4min:3min) Comparison: exercise, dietary and psychological advice, twice a month for 12 months	50% Follow-up testing occurred at 3 and 12 months

Heart rate monitoring was used in the majority of studies (14 out of 20; 70%) to ensure appropriate exercise intensity [24-32, 34, 35, 37, 38, 40]. Other studies used maximal oxygen uptake, [35], maximal aerobic speed [23], ventilatory threshold [50], echocardiography [47], individual anaerobic threshold velocity [44], distance covered [18 38 39], and energy expenditure [45]. One study monitored participants' perceived exertion levels [35].

Study follow-up periods primarily occurred immediately post-intervention (i.e., 19 out of 20 studies conducted follow-up assessments within one week of intervention completion). However, one study also conducted assessments at 3-months and 12-months post intervention [46].

Table 2: Fitness outcome measures

Study	HIIT post-test mean (SD)	Comparison group post-test mean (SD)
Cardiorespiratory fitness [VO_2 max (ml ·kg–1· min–1)]		
Boer 2014	31.4(4.8)	27.4(4.6)
Impellizzeri 2006	61.8(4.5)	60.2(3.9)
Ingul 2010	32.8(6.6)	51.5(7.8)
Racil 2013	39.7(1.8)	38.6(1.4)
Sandbakk 2011	70.2(6.8)	70.3(7.3)
Sperlich 2011	58.9(4.7)	56.4(3.7)
Tjonna 2009	36.0(1.1)	31.9(1.0)
Koubaa 2013	42.9(1.7)	39.2(3.2)
Gutin 2002*	1.7(0.6)*	0.4(0.7)*
Muscular power [counter movement jump (cm)]		
Banquet (2001)	158.2(2.6)	168.1(26.7)
Buchan (2011b)	33.6(6.2)	30.4(5.3)
Buchan (2013)	31.7(7.1)	29.7(6.3)
Buchheit (2009)	42.0(8.4)	39.3(7.7)
Faude (2013)	36.3(5.0)	38.1(4.7)
Sperlich (2011)	29.0(6.0)	34.0(7.0)
Body composition (BMI)		
Banquet (2011) Boys	19.6(3.4)	19.8(3.2)
Banquet (2011) Girls	20.1(3.5)	20.9(3.8)
Boer (2014)	27.7(4.7)	26.9(2.9)
Buchan (2013)	21.3(2.3)	22.3(2.5)
Buchan (2012)	21.3(2.1)	22.4(2.5)
Buchan (2011)	21.31(2.1)	22.31(2.5)
Farah (2014)	32.0(1.8)	33.9(1.7)
Koubaa (2013)	29.4(3.1)	28.5(2.6)
Tjonna (2009)	31.4(0.5)	32.9(0.5)
Body composition (body fat %)		
Banquet (2011) Boys	19.1(9.1)	18.0(7.2)
Banquet (2011) Girls	19.3(7.1)	25.3(9.1)
Boer (2014)	30.4(7.0)	32.0(7.0)
Buchan (2012)	17.2(3.6)	17.2(7.7)
Buchan (2011)	19.2(5.8)	16.6(7.2)
Farah (2014)	34.8(0.7)	38.2(2.6)
Racil (2013)	34.3(1.7)	35.4(1.2)
Tjonna (2009)	38.6(0.7)	39.1(0.6)
Gutin (2002)*	3.6(0.8)*	0.2(0.6)*
Body composition (waist circumference (cm)		
Boer (2014)	91.5(13.1)	95.9(8.2)
Buchan (2013)	75.3(6.7)	75.4(6.2)
Farah (2014)	91.3(3.8)	96.4(4.6)
Koubaa (2013)	96.3(9.9)	94.3(8.7)
Racil (2013)	90.3(6.7)	92.8(3.7)
Tjonna (2009)	98.1(2.2)	100.1(2.3)

Note: *=Change in CRF/BF%

Risk of bias results

Methodological 'risk of bias' scores are provided in Table 3. Initial agreement between reviewers was high (96%) for the 160 items and all of the studies were found to have moderate to high risk of bias. Eligibility criteria was specified in the majority of studies (14 out of 20) [24-26, 28, 30, 31, 33-40], while 12 of the 20 studies adequately reported similarities in primary outcomes at baseline [9, 25-28, 30, 31, 34, 35, 37, 40, 42]. Assessor blinding was only reported in two studies [24, 40]. Six studies adequately described the results for each group and provided the estimated effect size and its precision [24, 28, 30, 31, 37, 38]. Of the 20 studies, 12 clearly described and adequately completed the randomisation process [22, 24-26, 28-30, 33, 35, 38, 40, 42]. Only one study reported data for primary outcomes that were analysed following the 'intention to treat' principle [26]. Adequate retention (<20% dropout) was reported in six studies [24, 27, 31, 37, 39, 42], and four studies reported power calculations [30, 31, 37, 42].

Meta-analysis

Cardiorespiratory fitness

Eight studies were included in the meta-analysis examining the effect of HIIT on cardiorespiratory fitness. Overall, there was little evidence of heterogeneity (Q = 9.77, I^2 = 28.3%, p = .202) and the intervention effect from random effects model was statistically

Table 3: Risk of Bias Assessment

Study	Criteria A	Criteria B	Criteria C	Criteria D	Criteria E	Criteria F	Criteria G	Criteria H	Total
Banquet 2001	x	x	x	?	x	x	x	?	0
Boer 2014	✓	x	?	?	x	✓	?	?	2
Buchan 2011b	x	?	✓	x	x	✓	?	x	2
Buchan 2013	✓	✓	✓	x	x	?	✓	✓	5
Buchan 2011a	✓	✓	✓	x	x	x	?	✓	4
Buchan 2012	x	✓	?	x	x	x	?	?	1
Buchheit 2009	✓	?	✓	x	x	✓	✓	✓	5
Buchheit 2008	x	✓	✓	x	x	✓	✓	?	4
Farah 2014	✓	✓	✓	✓	x	x	?	?	4
Faude 2008	x	✓	?	x	x	x	?	?	1
Faude 2013	✓	✓	?	x	?	?	?	?	2
Gutin 2002	✓	✓	✓	?	✓	x	?	x	4
Impellizzeri 2008	✓	✓	✓	?	?	x	?	x	3
Impellizzeri 2006	✓	✓	?	✓	?	✓	?	✓	5
Ingul 2010	✓	x	x	x	x	?	x	x	1
Koubaa 2013	x	x	✓	x	x	?	x	x	1
Racil 2013	✓	✓	x	?	?	?	x	✓	3
Sandbakk 2011	✓	x	✓	?	?	✓	✓	x	4
Sperlich 2011	✓	x	✓	?	?	x	x	✓	3
Tjonna 2009	✓	✓	✓	?	?	x	x	x	3

Criteria: (a) Eligibility criteria were specified; (b) Participants were randomly allocated to groups; (c) The groups were similar at baseline regarding the primary outcome(s); (d) There was blinding of all assessors who measured the primary outcome(s); (e) Data for primary outcome(s) were analysed by 'intention to treat'; (f) Dropout for primary outcome(s) described, with <20% dropout of participants; (g) Sample size calculations were conducted and the study was adequately powered to detect changes in the primary outcome(s); and, (h) Summary results for each group plus estimated effect size (difference between groups) and its precision (e.g., 95% CI) were reported.

Coding: "explicitly described and present" (✓), "absent" (x) or "unclear or inadequately described" (?)

significant [unstandardized mean difference (MD) = 2.6 ml ·kg–1· min–1, 95% CI = 1.8 to 3.3, $p < .001$] and the summary effect size was large ($d = 1.05$, 95% CI = .36 to 1.75) (Figure 2). Study duration ($p = .480$), type of comparison group ($p = .738$) and risk of bias ($p = .306$) were not significant moderators of HIIT effects on cardiorespiratory fitness.

Muscular fitness

Five studies were included in the muscular fitness meta-analysis. There were moderate levels of heterogeneity among studies ($Q = 7.3$, $I^2 = 45.2\%$, $p = .121$) and the overall effect of HIIT was not statistically significant (MD = 0.8cm, 95% CI = -1.8 to 3.4, $p = .530$). The summary effect size was small ($d = 0.21$, 95% CI = -.07 to .50). Study duration ($p = .455$) and risk of bias ($p = .317$) were not significant moderators of HIIT training effects. However, type of comparison group was a moderator ($p = .057$), with larger effects observed for studies that included a non-training control group (2.5 cm, 95% CI = .3 to 6.7, $p = .027$), compared to those that included moderate intensity training groups (-1.3 cm, 95% CI = -5.4 to 2.8, $p = .545$).

Body composition

Eight, seven and six studies were included in the meta-analyses for BMI, body fat, and waist circumference, respectively. The summary effect for BMI was moderate ($d = -.37$, 95% CI = -.68 to -.05) and statistically significant (MD = -.6 kg.m-2, 95% CI = -.9 to -.4, $p < .001$). Low levels of heterogeneity were found ($Q = 7.0$, $I^2 = 0\%$, $p = .540$) (Figure 3). Type of comparison group ($p = .626$), study duration ($p = .305$) and risk of bias ($p = .227$) were not significant moderators of training effects.

The summary effect for body fat % was moderate ($d = -.67$, 95% CI = -1.30 to -.04) and statistically significant (MD = -1.6 %, 95% CI = -2.9 to -0.5, $p = .006$). High levels of heterogeneity were observed ($Q = 19.0$, $I^2 = 63.1\%$, $p = .008$) (Figure 4). Type of comparison group (p = .597) and risk of bias were (p = .410) were not significant moderators of training effects. However, study duration (p = .058) was a significant moderator of effects, with larger effects observed in studies ≥8 weeks (MD = -2.1%, 95% CI = -3.3 to -.8, p = .001), compared to those <8 weeks in duration (MD = 1.2%, 95% CI = -1.6 to 4.1, p = .399). Intervention effects for waist circumference were small (d = -.24, 95% CI = -.69 to .24) and not statistically significant (MD = -1.5 cm, 95% CI = -4.1 to -1.1, p = .264). High levels of heterogeneity were observed (Q = 15.7, I^2 = 68.2%, p = .008). No significant moderators were observed.

Publication bias

Rosenthal's *classic fail-safe N* was high for cardiorespiratory fitness (N = 155) and moderate for body fat (N = 45) and BMI (N = 23). Therefore, a relatively large number of studies with a mean effect of zero would be necessary before the overall effects found in the meta-analyses would no longer be statistically significant.

DISCUSSION

These meta-analyses have revealed that HIIT can significantly improve cardiorespiratory fitness, BMI and body fat percentage, in comparison to moderate intensity training and non-training control group conditions. However, the effects of HIIT on waist circumference and muscular fitness were not statistically significant and no studies reported their effect on flexibility. A secondary aim was to identify moderators of HIIT effects in studies involving adolescents. One significant moderator emerged, but length of study emerged as a moderator for body fat percentage (p = .058), with larger effects evident in studies ≥8 weeks compared to those <8 weeks in duration.

There is a dearth of studies examining the utility of HIIT to improve health-related fitness in adolescents. Of only 20 eligible studies, all had moderate to high risk of bias. Few studies reported assessor blinding for the measurement of primary outcomes [24, 40], or adequately described the statistical analyses to determine if analyses were conducted following the 'intention to treat' principle [26]. Sample size calculations for primary outcomes were rarely reported [30, 31, 37, 42]. The majority of studies included small sample sizes and limited generalisability (i.e., 19 out of the 20 studies had a sample size <100).

Cardiorespiratory fitness

HIIT has the potential to improve cardiorespiratory fitness in adolescent populations (unstandardized mean difference (MD) = 2.6 ml ·kg–1· min–1, 95% CI = 1.8 to 3.3, $p <$ .001). Our findings extend a review that examined the effect of school-based physical activity on fitness for children and adolescents, which reported statistically significant effects for VO_2 max in their meta-analysis ranging from 1.6 to 3.7 mL/kg per min[43]. There is now sufficient evidence to conclude that young people must engage in vigorous physical activity to improve their cardio-respiratory fitness[44]. However, promoting exercise adherence to vigorous activity is challenging and the majority of physical activity and fitness interventions targeting adolescents have resulted in null findings[43]. Traditional endurance training methods involve large training loads that require a substantial time commitment, which may be less appealing for 'time poor' adolescents. HIIT, on the other hand, can be completed quickly and results in similar or greater improvements in cardio-respiratory fitness compared to traditional endurance training.

Body composition

HIIT can improve body composition in adolescents and we observed a medium effect size (d = -.37) for BMI (MD = -.6 kg.m-2, 95% CI = -.9 to -.4, p <.001). The summary effect of HIIT is considerably larger than the effects of previous obesity prevention and physical activity interventions on body composition in young people. For example, a recent Cochrane review of 32 studies [43] examining the effect of obesity prevention interventions in adolescent populations, reported a non-significant summary effect of MD = -.09kg/m^2 [45]. Similarly, a review of the effectiveness of school-based physical activity interventions reported a summary effect of MD = -.05 kg/m^2; 95% CI -.19 to .10 [46]. However, the majority of HIIT studies have been conducted over relatively short periods of time and the longer term adherence and effects are not known. A medium effect size (d = -.67) was also observed for body fat percentage (MD = -1.6 %, 95% CI = -2.9 to -.5, p = .006). Study duration emerged as a moderator for body fat, indicating greater effects in HIIT interventions of ≥8 weeks. The effect of HIIT on waist circumference was not statistically significant (MD = -1.5 cm, 95% CI = -4.1 to -1.1, p = .264). The null findings may reflect measurement error and the challenges of accurately measuring waist circumference in adolescent populations [47].

Muscular fitness

The summary effect of HIIT on muscular fitness was small and not statistically significant. For example, Faude and colleagues [33] reported muscular fitness (jump height assessed using vertical counter movement jump) declined significantly over the 5.5 week study period for both HIIT and high volume groups (p < .003). Such findings reflect lack of training specificity in the HIIT protocols that have predominantly involved running and sprinting, which are more likely to improve other components of fitness (e.g., speed, cardio-respiratory fitness and body composition). The inclusion of resistance-based exercise in addition to aerobic activity may assist in improving muscular fitness in future HIIT studies.

Future direction

There is a need for high-quality studies that include longer-term follow-up assessments to determine whether or not adolescents will adhere to HIIT protocols for extended periods of time (> 1 year). Limitations of previous studies include lack of assessor blinding, failure to following the intention to treat principle, and absent power calculations for the primary outcome(s). Compared to previous obesity prevention and physical activity interventions, HIIT is an efficacious strategy for increasing cardio-respiratory fitness and improving body composition in adolescents. Although the generalisability of these findings are limited due to the unique study populations included in this review, it is plausible to suggest that HIIT may have utility for improving population levels of body composition if it can be delivered in settings that have considerable reach to all adolescents, such as secondary schools. Future studies are encouraged to assess the utility of embedding HIIT within the school day (e.g., in physical education or adapting for the classroom). Future studies should include strength training exercises into HIIT programs for developing muscular fitness.

There is an opportunity to examine the impact of HIIT on mental health outcomes such as depression, self-esteem and cognitive functioning. Fitness may provide protection against mental illness in both adolescence and adulthood [48]. A Swedish longitudinal study, which tracked a cohort of over 1 million men with no history of mental illness, found that lower cardio-respiratory fitness at age 18 was associated with increased risk of serious depression in adulthood. Also, the benefits of physical activity on academic performance have been identified for other modes of exercise (e.g., endurance training), therefore it would be worthwhile for future studies to examine the specific effect of HIIT on academic performance and/or cognitive function.

Strengths and limitations

This is the first systematic review and meta-analysis of studies examining the utility of HIIT to improve health-related fitness outcomes among adolescents. Strengths include the use of criteria for assessing study risk of bias adapted from the PRISMA statement [18] and high percentage agreement for risk of bias assessment. Limitations include the potential of publication bias as studies were required to be published in English and we did not include grey literature (e.g., theses, dissertations). Limitations of the field also exist, for example, all of the studies included in the review had medium to high risk of bias as outlined in the discussion, and no studies meeting inclusion criteria examined the effect of HIIT on flexibility.

CONCLUSION

HIIT is a feasible and time efficient approach for improving cardiorespiratory fitness and body composition in adolescents. Our meta-analysis provides evidence of statistically significant improvements in cardiorespiratory fitness, BMI and body fat percentage for adolescents following HIIT interventions. Intervention duration of ≥8 weeks emerged as a moderator for body fat percentage, but not for the other fitness outcomes examined.

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AUTHOR CONTRIBUTIONS

SAC: Conducted literature search, assessed studies for eligibility, conducted risk of bias assessment, writing of manuscript.

NE: Assessed studies for eligibility, conducted risk of bias assessment, participated in drafting and revising the article.

RCP: Participated in drafting and revising the article, data checking.

DT: Participated in drafting and revising the article.

DRL: Conception and design of review, conducted data analysis (meta-analysis) and interpretation, participated in drafting and revising the article.

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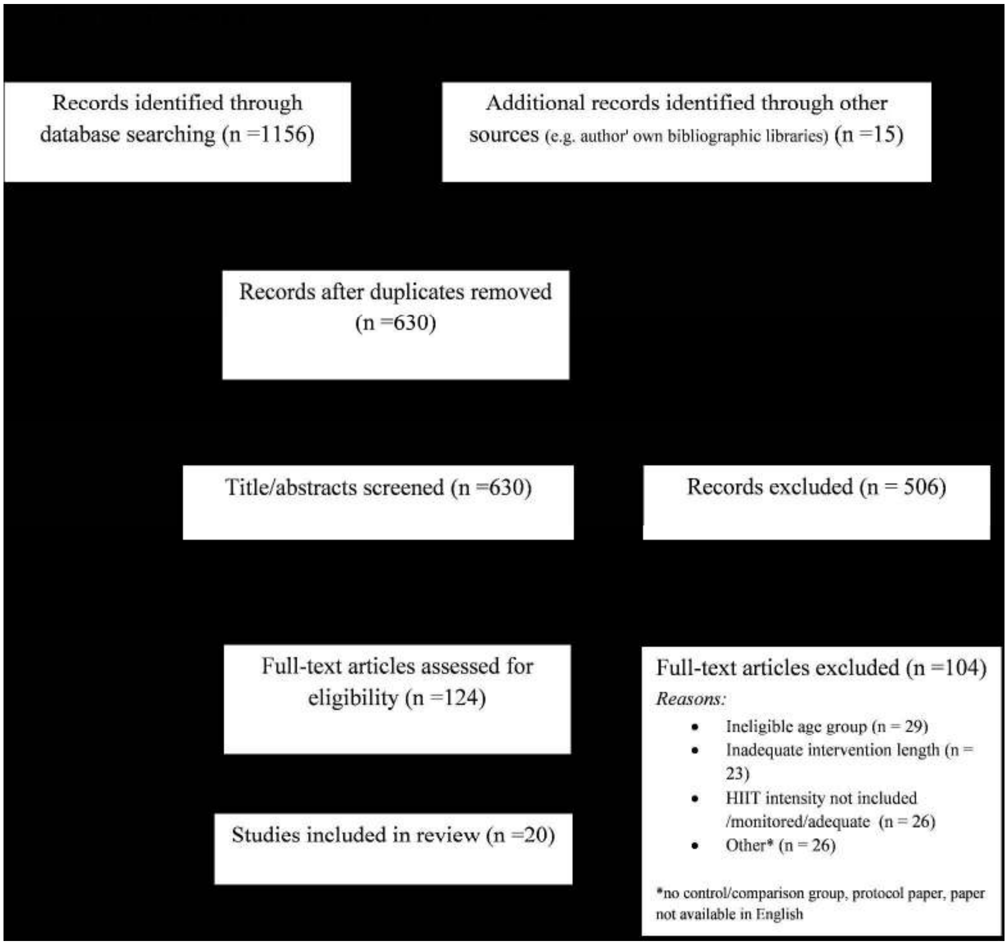

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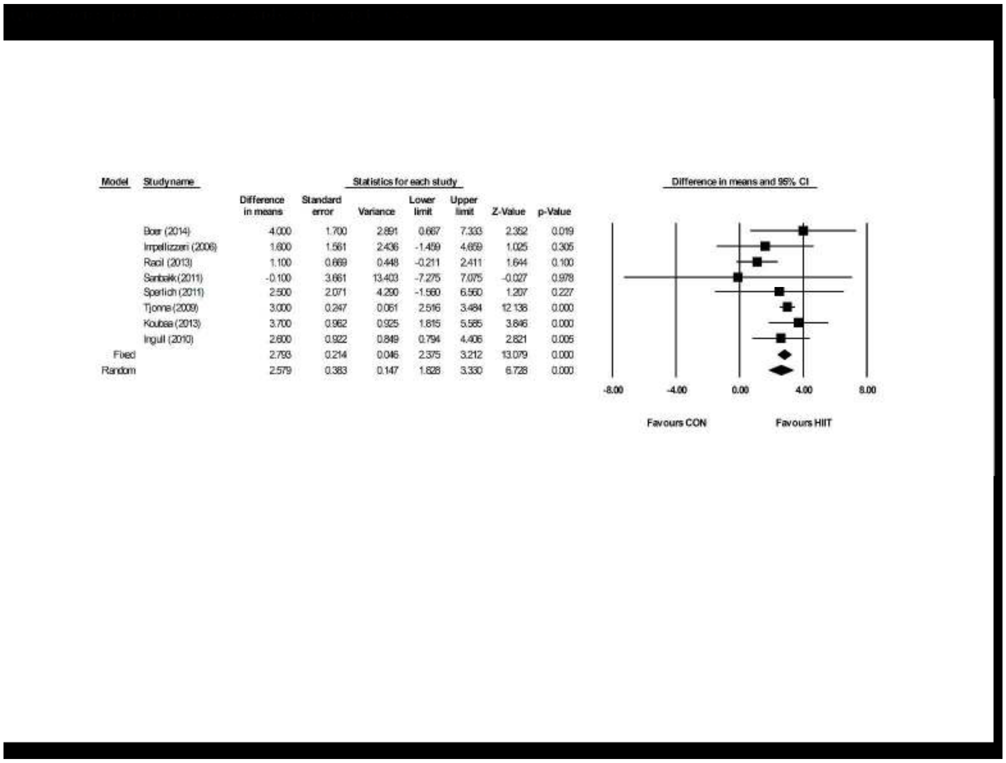

Model	Studyname	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Boer (2014)	4.000	1.700	2.891	0.667	7.333	2.352	0.019
	Impellizzeri (2006)	1.600	1.561	2.436	-1.459	4.659	1.025	0.305
	Racil (2013)	1.100	0.669	0.448	-0.211	2.411	1.644	0.100
	Sanbakk (2011)	-0.100	3.661	13.403	-7.275	7.075	-0.027	0.978
	Sperlich (2011)	2.500	2.071	4.290	-1.560	6.560	1.207	0.227
	Tjonna (2009)	3.000	0.247	0.061	2.516	3.484	12.136	0.000
	Koubaa (2013)	3.700	0.962	0.925	1.815	5.585	3.846	0.000
	Ingull (2010)	2.600	0.922	0.849	0.794	4.406	2.821	0.005
Fixed		2.793	0.214	0.046	2.375	3.212	13.079	0.000
Random		2.579	0.383	0.147	1.828	3.330	6.728	0.000

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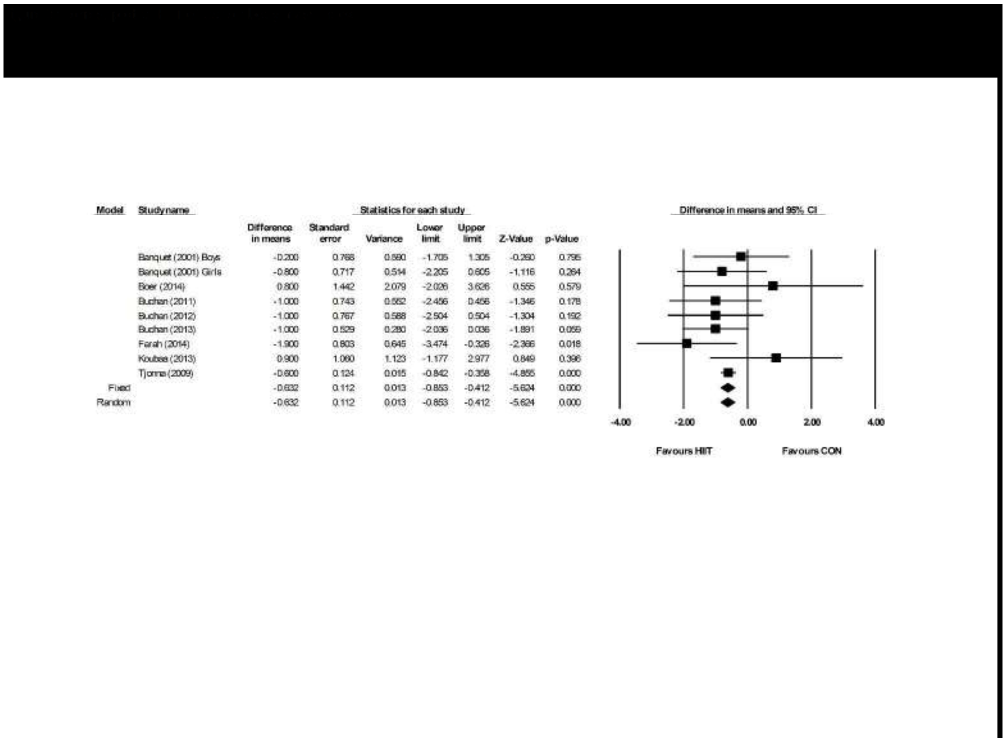

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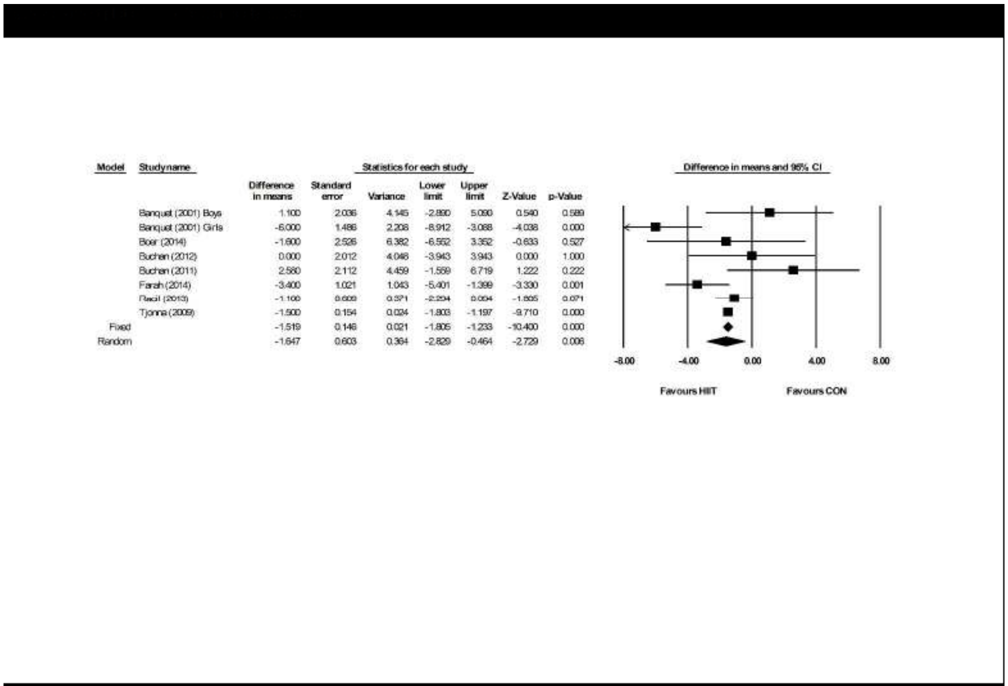

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