Cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents; what level of fitness should raise a red flag? A systematic review and meta-analysis

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ABSTRACT

Background Poor cardiorespiratory fitness is associated with cardiovascular disease risk factors.
Aim To perform a systematic review and meta-analysis of the relationship between poor cardiorespiratory fitness and cardiovascular disease risk in children and adolescents.
Methods Systematic literature search (1980 to 11 April 2015) for studies that determined a cardiorespiratory fitness cut point that predicted cardiovascular disease risk in children and adolescents.
Results We identified 7 studies that included 9280 children and adolescents (49% girls) aged 8–19 years from 14 countries. Cardiovascular disease risk was already present in boys (6–39%) and girls (6–86%). Boys with low fitness (<41.8 mL/kg/min) had a 5.7 times greater likelihood of having cardiovascular disease risk (95% CI 4.8 to 6.7). The comparable diagnostic OR for girls with low fitness (<34.6 mL/kg/min) was 3.6 (95% CI 3.0 to 4.3). The 95% confidence region of cardiorespiratory fitness associated with low cardiovascular disease risk ranges, 41.8–47.0 mL/kg/min in boys (eg, stages 6–8 for a boy aged 15 years) and 34.6–39.5 mL/kg/min in girls (eg, stages 3–5 for a girl aged 15 years). The cardiorespiratory fitness cut point to avoid cardiovascular disease risk ranged 41.8 mL/kg/min in boys and was 34.6 mL/kg/min in girls.
Summary Fitness levels below 42 and 35 mL/kg/min for boys and girls, respectively, should raise a red flag. These translate to 6 and 3 stages on the shuttle run test for a boy and a girl, both aged 15 years, respectively. These cut points identify children and adolescents who may benefit from primary and secondary cardiovascular prevention programming.

INTRODUCTION

Cardiovascular disease is the leading cause of global mortality. The precursors of cardiovascular disease have its origin in childhood.[1] Cardiovascular disease risk factors during childhood and adolescence are associated with more extensive fatty streaks and fibrous plaques in adults,[1] with artery calcification in young adults[2] and with common artery intima media thickness in adulthood.[3] The most recognised cardiovascular disease risk factors in children and adolescents are triglycerides, total cholesterol (TC), high-density lipoprotein cholesterol (HDL), insulin, glucose, waist circumference and blood pressure.[4–8]

Cardiorespiratory fitness reflects (1) the overall capacity of the cardiovascular and respiratory systems and (2) the ability to carry out prolonged, rhythmic and dynamic exercise involving large muscles of the body.[9] It is a direct measure of aerobic functional capacity. There is an unequivocal association between poor cardiorespiratory fitness and cardiovascular disease risk factors in children and adolescents.[10] Children and adolescents with low cardiorespiratory fitness have higher risk of cardiovascular disease[11] and myocardial infarction during adulthood.[12] Children and adolescents with low cardiorespiratory fitness also have low fitness levels years later.[13]

Cardiorespiratory fitness has historically been included in almost all children and adolescents fitness test batteries.[14] Cardiorespiratory fitness test scores were originally tracked as a marker of performance, but the increasing focus on health-related fitness has led to its use as a screening test to identify children and adolescents at increased risk of cardiovascular disease.[15–17] The Fitnessgram program in the USA has even used the fitness criterion-referenced standards to provide individualised feedback on cardiovascular risk on student reports; this is uncommon in other countries. Although fitness is widely used in schools and children and adolescents programming, clinicians or other health agencies that evaluate present or future cardiovascular disease risk at these ages have not adopted these standards.

Three barriers to health professionals/public health adopting fitness testing to evaluate health are the lack of standardisation in (1) the test protocols and (2) the health outcomes being evaluated, as well as (3) the absence of evidence-based clinical cut points at these ages. To facilitate fitness testing to assess cardiovascular disease risk in clinical settings and in schools, it is important to work towards international standards similar to those developed for body composition.[18]

Thus, the aim of this meta-analysis was to systematically evaluate the relationship between low cardiorespiratory fitness and cardiovascular disease risk in children and adolescents from several countries. Specifically, we addressed the question: are there cardiorespiratory fitness cut points associated with cardiovascular disease risk in children and adolescents? The goal was to identify what fitness level should raise a red flag. We aimed to provide pooled fitness cut points that could serve as standards for international comparisons and for clinical applications.

METHODS

Search strategy and study selection

We followed the checklist of the Meta-analysis of Observational Studies in Epidemiology[19] and the recommendations of the Cochrane Collaboration Handbook.[20] We conducted a systematic literature search of MEDLINE, EMBASE, The Cochrane Library, Web of Science and SPORTDiscus (1980 to 11 April 2015) for studies that determined the cardiorespiratory fitness cut point associated with cardiovascular disease risk. We combined three search topics using the Boolean operator *AND*. The first key words were related to children and adolescents as follows: 'adoles* OR child* OR schoolchildren'. The second key words were related to cardiorespiratory fitness: 'cardiorespiratory fitness OR cardiovascular fitness OR aerobic capacity OR aerobic fitness OR maximal oxygen consumption OR VO_{2max} OR VO_{2peak}'. The third keywords were related to the outcome of this meta-analysis: 'cardiovascular disease OR cardiovascular disease risk OR cardiovascular health OR metabolic syndrome OR metabolic risk OR cardiometabolic risk OR insulin resistance OR dyslipidemia OR hypertension OR blood pressure OR diabetes mellitus'. In addition, we searched the reference lists of all identified relevant publications.

Inclusion criteria

Two reviewers (IC-R and JRR) independently examined the title and abstract of each reference to identify those studies that were likely to report the cardiorespiratory fitness (VO_{2max}, mL/kg/min) cut point and then obtained the full text. Disagreements about study selection were resolved by consensus with a third reviewer (VM-V). The full text was retrieved for articles that could not be excluded based on title and abstract to determine final inclusion.

We included studies if: (1) the age range of participants was between 8 and 19 years; (2) data were reported by sex; (3) cardiorespiratory fitness was assessed by a submaximal or maximal exercise test and can be expressed as VO_{2max} (mL/kg/min); (4) a cardiorespiratory fitness cut point associated with cardiovascular disease risk was calculated in the study; (5) at least two cardiovascular disease risk factors were measured and (6) definition of cardiovascular disease risk are provided. No restrictions were considered regarding study design (cross sectional, case–control, cohort study) or data collection (prospective or retrospective).

To avoid duplicate data, we identified articles that included the same group of participants by reviewing interstudy similarity in any of the following characteristics: country in which the study was conducted, investigators who performed the study, source of patients, recruitment period and inclusion criteria. When the same investigators reported results obtained on the same group of patients in several publications, only the largest series was included in the analysis.

Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) criteria[21] were used to standardise the assessment of the quality of the included studies. This 7-item tool has been proposed for the quality evaluation of included studies in meta-analyses of diagnostic accuracy and categorises the risk of bias and the study generalisability as low, unclear or high. Both reviewers scored independently the seven items of QUADAS-2 (IC-R and JRR), and disagreements were resolved via consensus with a third reviewer (VM-V).

Data extraction and synthesis

Two authors (IC-R and JRR) independently reviewed each published study and extracted the following information: first author's name, year of publication, study name, country of origin, cardiovascular disease risk factors, definition of cardiovascular disease risk, cardiorespiratory fitness test used to estimate VO_{2max}, participants' sex and age, number of participants, cardiorespiratory fitness cut points associated with cardiovascular disease risk, prevalence of cardiovascular disease risk, sensitivity, specificity and area under the curve (AUC). Any disagreement was resolved by consensus with a third reviewer (VM-V).

Statistical analyses

The diagnostic OR (dOR) was computed by the Moses' constant of linear model and in the context of a random effects model. This approach relies on the linear regression of the logarithm of the dOR of a study (dependent variable) on an expression of the positivity cut point of that study (independent variable).[22] The dOR is a single indicator of test accuracy that combines the sensitivity and specificity data into a single number.[11]

Study heterogeneity was assessed with an I^2 statistic. A large I^2 value indicates that data are not consistent with a simple pooling model; a more sophisticated model is needed to properly combine the data. Accordingly, a random-effects model based on the Der Simonian and Laird method was used to model test performance and account for heterogeneity among studies not attributable to observed study characteristics. Cardiorespiratory fitness (VO_{2max}) test performance in the presence of heterogeneity was summarised using hierarchical summary receiver operating curves (HSROC).[23]

The influence of each independent study in the pooled estimates of dOR was detected by sensitivity analysis. For assessing the potential publication bias, we used the funnel plot proposed by Deeks et al,[24] which visually assess publication bias by using a scatter plot of the inverse of the square root of the effective sample size ($1/ESS^{1/2}$) versus the diagnostic logit dOR (logdOR), which should have a symmetrical funnel shape when publication bias is absent. The degree of asymmetry in the plot was statistically evaluated by a regression of the logit dOR against $1/ESS^{1/2}$, weighted by ESS. Additionally, the pooled sensitivity, specificity, positive likelihood ratio (PLR) and negative likelihood ratio (NLR) for cardiorespiratory fitness (VO_{2max}) test (pooled across studies) and their 95% CIs were calculated.[25]

All analyses were undertaken using STATA V.13.0 (STATA Corp, College Station, Texas, USA).

RESULTS

Literature search and study characteristics

Figure 1 shows the number of studies that were identified and excluded at different stages of the selection process. Seven studies were included in the present meta-analysis,[17] [26–31] including 9280 children and adolescents (4717 boys and 4563 girls) aged 8–19 years from 14 countries (table 1). The list of cardiovascular disease risk factors measured in the included studies and the definition of cardiovascular disease risk are shown in table 1. One study did not provide the prevalence of cardiovascular disease risk[28] in girls, and two studies provided information for two different age groups.[29] [30] The prevalence of cardiovascular disease risk ranged from 6% to 39% in boys and from 6% to 86% in girls.

Study quality

All included studies were assessed as low risk of bias in terms of both domains of the QUADAS-2 tool, the reference standard and flow and timing criteria. One study scored high risk of bias in terms of the index test (VO_{2max}).[24] One study was rated as unclear risk of bias in selection of participants' criterion.[29]
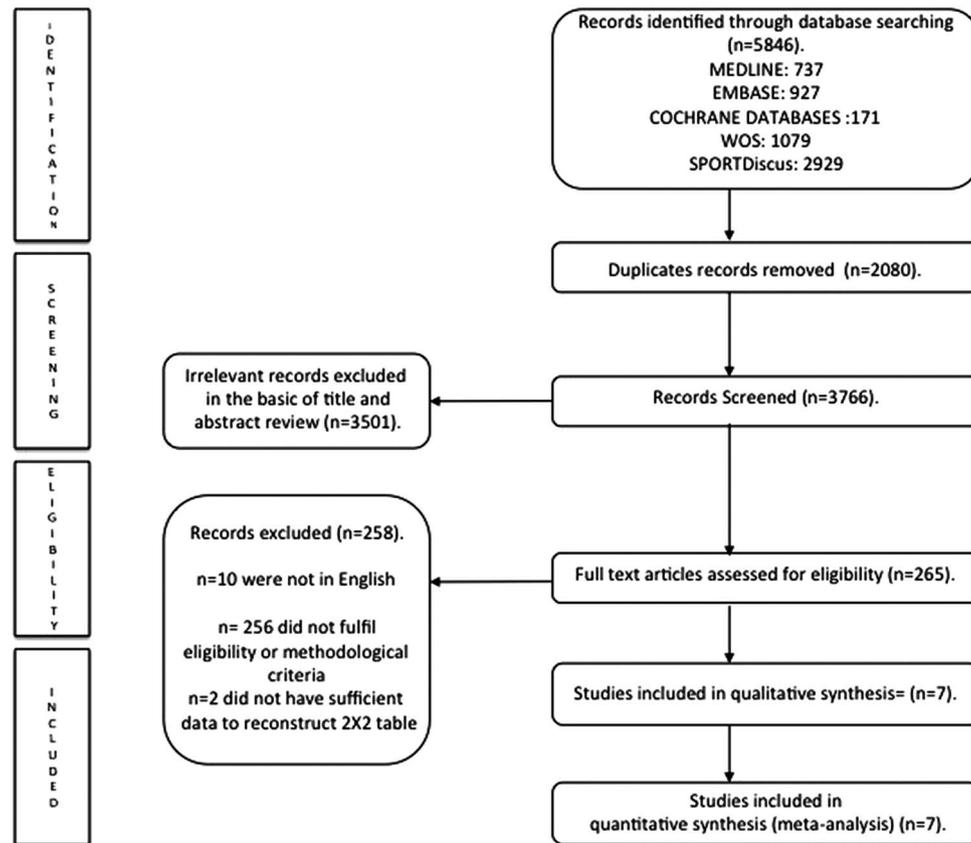
Figure 1 Selection of articles for meta-analysis.

Three studies scored unclear concerns regarding applicability in participants' selection,[31 37 38] and six studies were rated as unclear concerns regarding applicability in the index test[28 31 37–39] (see online supplementary figure S1).

Meta-analysis

Table 2 shows the pooled sensitivity, specificity, PLR, NLR, dOR and AUC estimates for boys and girls. Overall, the pooled sensitivity estimates for cardiorespiratory fitness were 65.0 (95% CI 60.0 to 71.0) for boys and 60.0 (95% CI 56.0 to 65.0) for girls, and the pooled specificity estimates were 77 (95% CI 74 to 80) for boys and 74 (95% CI 72 to 77) for girls. Moreover, the pooled PLR and NLR for boys were 2.81 (95% CI 1.18 to 6.70) and 0.39 (95% CI 0.17 to 0.92), respectively, and for girls these estimates were 2.05 (95% CI 0.78 to 5.39) and 0.44 (95% CI 0.17 to 1.14), respectively. What do these results mean given a 20% prevalence of cardiovascular disease (200/1000)? Boys and girls with fitness levels falling in the healthy ranges (see below) have a probability of 89.9% and 88.2%, respectively, of not having cardiovascular disease risk.

Figure 2 displays the forest plots of dOR by sex. An unadjusted pooled analysis of the studies showed evidence of significant heterogeneity among studies in boys dOR (I^2 of 66%) and in girls dOR (I^2 of 79%). The pooled dOR estimates were 5.7 (95% CI 4.8 to 6.7) for boys and 3.6 (95% CI 3.0 to 4.3) for girls, which indicates that boys with low fitness (<41.8 mL/kg/min) had a 5.7 times greater likelihood of having cardiovascular disease risk compared to those with the fitness level equal or higher than 41.8 mL/kg/min. Similarly, girls with low fitness (<34.6 mL/kg/min) had a 3.6 times greater likelihood of having cardiovascular disease risk compared to those with the fitness level equal or higher

than 34.6 mL/kg/min. Additional forest plots and pooled accuracy parameters are provided in online supplementary figures S2–S5.

The area under the HSROC curve estimating the discriminating accuracy of cardiorespiratory fitness for identifying cardiovascular disease risk was 0.71 (95% CI 0.65 to 0.76; p<0.001) in boys and 0.64 (95% CI 0.58 to 0.69; p<0.001) in girls (figure 3).

The 95% CI region for the summary point included studies in which the cut point for cardiorespiratory fitness ranged from 41.8 to 47.0 mL/kg/min in boys and between 34.6 and 39.5 mL/kg/min in girls.

Sensitivity analyses and publication bias

Sensitivity analyses revealed that no studies unduly influenced the pooled estimates of dOR in boys. However, in girls, the pooled dOR estimates changed after removing data of both age group samples of the study by Adegboye et al;[30] when removed the 8–11 years old group, the dOR worsened (dOR=3.0; 95% CI 2.4 to 3.7), and when the 14–17 years old group was removed, it improved (dOR=4.4; 95% CI 3.6 to 5.3) (see online supplementary figure S6).

The Deek's funnel plot displayed a symmetric distribution of the points corresponding to each study (boys: intercept, 0.87; 95% CI −0.49 to 2.23; p=0.175; girls: for intercept, 0.55; 95% CI −1.40 to 2.50; p=0.515), indicating that publication bias was unlikely (see online supplementary figure S7). None of the included studies reported any adverse event.

DISCUSSION

The present meta-analysis documents the robust utility of cardiorespiratory fitness as a predictor of cardiovascular disease risk in children and adolescents. The consistency of findings

Table 1 Characteristics of studies included in the meta-analysis

Source (study)	Location	Cardiovascular disease risk factors	Definition of cardiovascular disease risk	Cardiorespiratory fitness test	Sex	Age (years)	N	Cardiorespiratory fitness cut points (mL/kg/min)	Prevalence of cardiovascular disease risk (%)	Sensitivity (%)	Specificity (%)	AUC (95% CI)
Mesa et al[28] (AVENA)	Spain	TC, LDL, Lp(a), HDL	≥1 factor with unhealthy level (TC >240 mg/dL; LDL >130 mg/dL; Lp(a) >32 mg/dL; HDL <35 mg/dL)	20 m shuttle run test VO_{2max} estimated[32]	Boys	13–18.5	248	45–47	38	73.4	73.4	0.72 (0.65 to 0.78)
					Girls	13–18.5	212	NA	NA	NA	NA	0.51 (0.42 to 0.59)
Ruiz et al[27] (EYHS)	Estonia and Sweden	Cardiovascular risk factors (insulin, glucose, HDL, TG, sum of five skinfolds, BP)	≥1 SD of a continuous standardised score computed with all CVD risk factors	Maximal cycle ergometer test. VO_{2max} estimated[33]	Boys	9–10	429	42	38	65	67	0.67 (0.61 to 0.73)
					Girls	9–10	444	37	44	65	61	0.68 (0.62 to 0.73)
Lobelo et al[29] (NHANES 1999–2002)	USA	Cardiovascular risk factors (systolic BP, triceps and subscapular skinfolds, HOMA, TG, TC/HDL)	>1 SD of a continuous standardised score computed with all CVD risk factors	Submaximal walking treadmill test. VO_{2max} estimated[34]	Boys	12–15[a]	308	44	31	58	87	0.77 (0.68 to 0.86)
						16–19[b]	369	40	37	82	54	0.72 (0.64 to 0.79)
					Girls	12–15[a]	315	36	30	64	66	0.54 (0.42 to 0.66)
						16–19[b]	255	36	33	84	44	0.54 (0.38 to 0.70)
Adegboye et al[30] (EYHS)	Denmark, Estonia, Portugal and Norway	Cardiovascular risk factors (systolic BP, TG, TC/HDL, HOMA, sum of four skinfolds)	>1 SD of a continuous standardised score computed with all CVD risk factors	Maximal cycle ergometer test. VO_{2max} estimated[33]	Boys	8–11[a]	1219	43.6	32	55.4	79.3	0.68
						14–17[b]	1049	46.0	41	55.6	86.4	0.55
					Girls	8–11[a]	1181	37.4	39	49.7	85.9	0.67
						14–17[b]	1051	33.0	19	29.7	79.9	0.69
Moreira et al[31]	Portugal	Cardiovascular risk factors (waist and hip circumference, glucose, TC, HDL, LDL, TG, BP)	≥1 SD of a continuous standardised score computed with all CVD risk factors	20 m shuttle run test. VO_{2max} estimated[35]	Boys	10–18	195	41.8	36	55.2	75.8	0.65 (0.58 to 0.72)
					Girls	10–18	255	39.5	86	55.6	78.2	0.65 (0.59 to 0.71)
Welk et al[17] (NHANES 1999–2002)	USA	Waist circumference, systolic BP/diastolic BP, HDL, TG, and glucose	≥3 CVD risk factors above the cut point of the NCEP Adult Treatment Panel III	Submaximal walking treadmill test. VO_{2max} estimated[34]	Boys	12–18	649	40–44	6	92.3	64	0.83
					Girls	12–18	591	38–40	6	92.8	62.7	0.77
Ruiz et al[26] (HELENA)	Greece, Germany, Belgium, France, Hungary, Italy, Sweden, Austria and Spain	Ideal cardiovascular health[36] (smoking, BMI, physical activity, diet, TC, BP, glucose)	Presence of ≥4 ideal cardiovascular health components	20 m shuttle run test. VO_{2max} estimated[32]	Boys	12.5–17.5	251	43.8	12	68.9	82.8	0.81 (0.73 to 0.88)
					Girls	12.5–17.5	259	34.6	17	74.9	59.1	0.69 (0.61 to 0.78)

AUC, area under the curve; %BF, per cent body fat; BMI, body mass index; BP, blood pressure; CRF, cardiorespiratory fitness; CV, cardiovascular; HDL, high-density lipoprotein cholesterol; HOMA, homeostasis model assessment; LDL, low-density lipoprotein cholesterol; Lp(a), Lipoprotein (a); NA, not available; NCEP, National Cholesterol Education Program; ROC, receiver operating characteristic; TC, total cholesterol; TG, triglycerides; WC, waist circumference.
Superscript letters a and b indicate different subgroups of participants in that study.

Table 2 Summary of the pooled accuracy parameters analysis for cardiorespiratory fitness by sex

	No. of studies	Sensitivity (%)	Specificity (%)	PLR	NLR	dOR	AUC
Boys	9	65.0 (60.0 to 71.0)	77.0 (74.0 to 80.0)	2.81 (1.18 to 6.70)	0.39 (0.17 to 0.92)	5.7 (4.8 to 6.7)	0.71 (0.65 to 0.76)
Girls	8	60.0 (56.0 to 65.0)	74.4 (71.5 to 77.4)	2.05 (0.78 to 5.39)	0.44 (0.17 to 1.14)	3.6 (3.0 to 4.3)	0.64 (0.58 to 0.69)

Values in parentheses are 95% CI.
AUC, area under receiver operating characteristic curve; dOR, diagnostic OR; NLR, negative likelihood ratio (the probability of a person who has the disease testing negative divided by the probability of a person who does not have the disease testing negative); PLR, positive likelihood ratio (the probability of a person who has the disease testing positive divided by the probability of a person who does not have the disease testing positive).
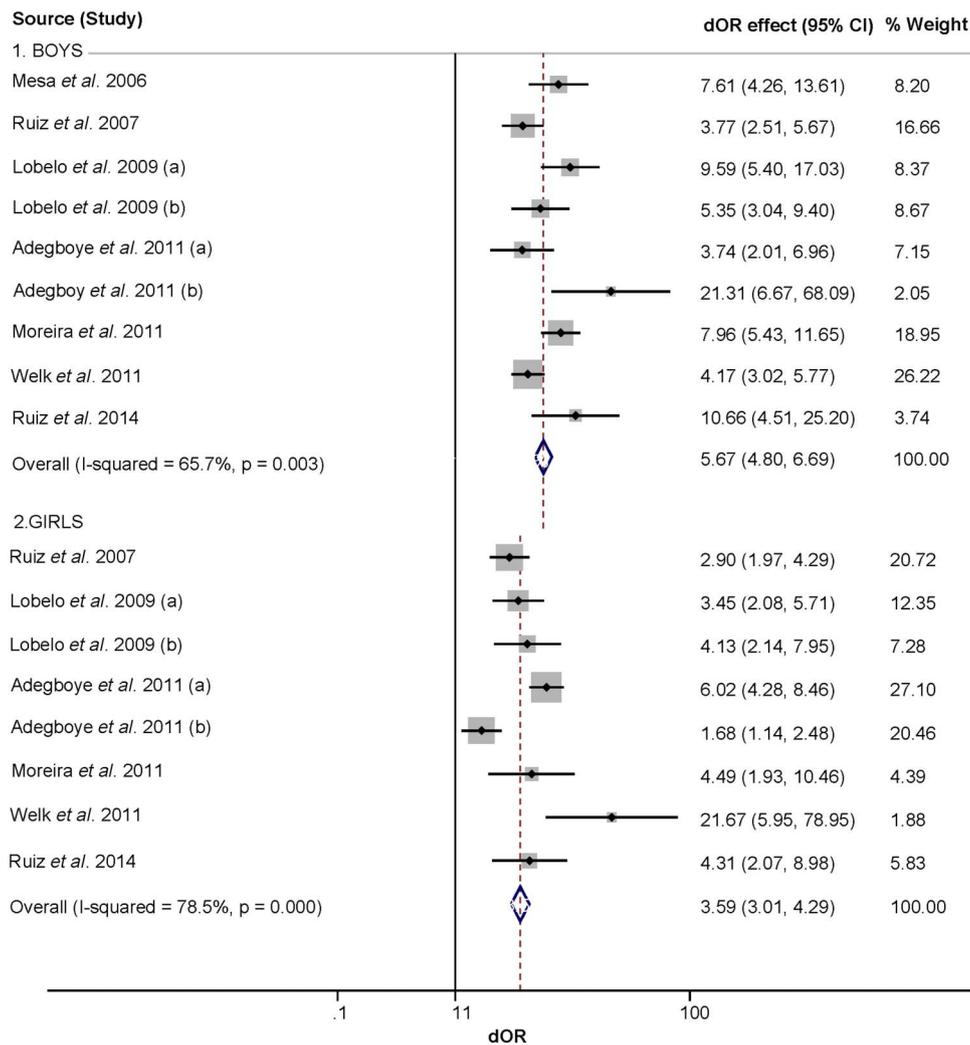

Figure 2 Pooled estimates dOR forest plot by sex. (A,B) Different subgroups of participants in that study, as defined by setting (table 1). dOR, diagnostic OR.

across countries supports the cross-cultural generalisability of these associations. Indeed, stability across studies is especially noteworthy considering inherent differences in (1) fitness test protocols (eg, laboratory and field-based tests, submaximal and maximal-effort tests), (2) prediction equations used to estimate cardiorespiratory fitness, (3) cardiovascular disease risk factors measured and (4) definitions of cardiovascular disease risk (table 1). This reinforces the existence of generalised cardiorespiratory fitness cut points associated with cardiovascular disease risk in children and adolescents.

Cardiovascular disease risk-related cut points
The fitness cut points to avoid cardiovascular disease risk fell between 41.8 and 47.0 mL/kg/min in boys aged 8–17 years and between 34.6 and 39.5 mL/kg/min in girls aged 8–17 years. In a hypothetical scenario of a population with a 20% prevalence of cardiovascular disease risk (200/1000), boys and girls with healthy fitness levels have a probability of 89.9% and 88.2%, respectively, of not having cardiovascular disease risk.

We found that the cardiorespiratory fitness cut point associated with cardiovascular disease risk was around 12 metabolic equivalents (12 METs, 42 mL/kg/min) for boys and 10 (10 METs, 35 mL/kg/min) for girls. Interestingly, the empirically derived values are similar to those used originally to identify fit versus unfit adolescents in the 90's by the Fitnessgram health-related fitness battery. They suggested a cardiorespiratory cut point of ≥38 and ≥42 mL/kg/min for girls and boys, respectively,[40] which were extrapolated from the adults' cut points
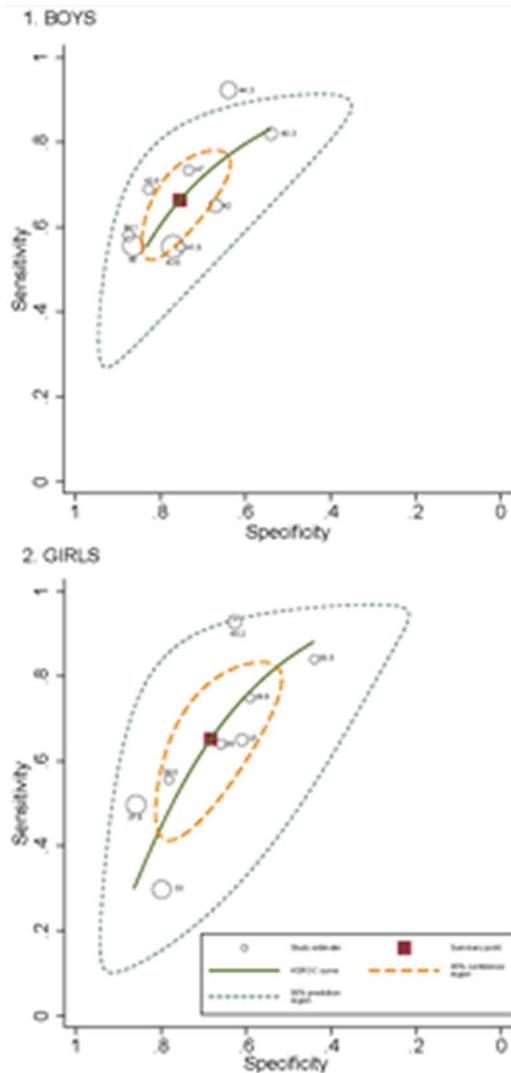
Figure 3 HSROC curve summarising the potential of cardiorespiratory fitness to identify cardiovascular disease risk by sex. The 95% confidence region for the summary point included studies in which the cut point for cardiorespiratory fitness ranged from 41.8 to 47.0 mL/kg/min in boys and between 34.6 and 39.5 mL/kg/min in girls. HSROC, hierarchical summary receiver operating characteristic.

associated with a higher risk of mortality. The current Fitnessgram standards vary across age to take growth and maturation into account,[17] but those fall within the same ranges highlighted here. These same standards also have similar predictive utility for detecting risk of metabolic syndrome in a nationally representative sample of Hungarian youth. In that study, youth who were unfit (23% of boys and 43% of girls) were 2.8 times more likely to have metabolic syndrome than their fit counterparts. These findings further document the cross-cultural generalisability of the cut points.[41]

Translating cardiorespiratory fitness standards into units that can influence public health

With the widely used 20 m shuttle run test,[42][43] the achievement of the health-related fitness cut point can be easily determined using age-specific and gender-specific tables (see table 3). To achieve the cardiorespiratory fitness cut points to avoid cardiovascular disease risk, a boy aged 15 years and a girl aged 15 years should run at 11 km/hour (stage 6) and 9.5 km/hour (stage 3), respectively. Cardiorespiratory fitness as measured by

this test has already been considered a relevant marker of current health,[10] as well as an indicator of future cardiovascular health.[11] It has been used in more than one million children and adolescents from about 50 countries.[43] Moreover, the test is used as the basis for personalised fitness reports in the USA and was endorsed by the National Academy of Medicine as an indicator of cardiorespiratory fitness for public health surveillance.[38] Of note is also that the test has a good validity,[14] and reliability,[44] and it is feasible and safe[37] for the assessment of cardiorespiratory fitness in children and adolescents. It is recommended to be used for health monitoring purposes at population level,[15] as well as in the school setting. The 20 m shuttle run test (with minimal adaptations) is also reliable and valid in children as young as 3–5 years old.[38][39] This test is part of the evidence-based ALPHA-fitness test battery for children and adolescents.[15]

Cardiorespiratory fitness and current and future youth's health

Findings from cross-sectional studies have shown that low cardiorespiratory fitness is not only associated with higher cardiovascular disease risk but also with decreased mental and skeletal health.[10][45] Moreover, data from longitudinal studies indicate that there is strong evidence that low cardiorespiratory fitness in childhood and adolescence is a predictor of cardiovascular disease risk later in life.[11] Poor cardiorespiratory fitness in childhood and adolescence has also been associated with higher risk of metabolic syndrome,[46] arterial stiffness[47][48] and myocardial infarction years later.[12] Levels of cardiorespiratory fitness tend to track from childhood to adolescence,[49][50] as well as from adolescence to adulthood.[13][51] Taken together, these findings support the notion that the promotion of high cardiorespiratory fitness levels should start at childhood.[13]

Settings to assess and improve fitness

Schools as well as sport clubs might be a convenient setting to promote a healthy lifestyle among young populations.[52] Schools could collect this information to encourage children to be more physically active to achieve and go beyond the suggested cardiorespiratory fitness cut points.[53] While this evaluation might not provide diagnoses per se, it could serve as screening element to identify young people with cardiovascular disease risk who might benefit from intervention programmes. Moreover, such screening can be used as a tool to teach youth about how to monitor and improve their fitness. Schools can play a leadership role to promote physical activity and health,[53] as well as to combat poor fitness among youth. There are indeed good examples on what can be performed at the school setting: McDonald and Trost[54] evaluated the efficacy of a school-based goal setting and self-monitoring intervention on aerobic fitness in middle school students and showed a significant increase in aerobic fitness over the 10-week period, whereas fitness levels among students participating in their usual school physical education declined. We suggest that children should be tested in physical education lessons using a cardiorespiratory field test, if possible every year. Testing could be used as a pedagogical tool for the physical education teacher to help children with poor fitness, as well as to keep encouraging being physically active to those with high fitness levels.

There are several examples of good practice in terms of monitoring body weight status and fitness among young US citizens.[55] Unfortunately, despite the relevant information provided by a relatively simple assessment of cardiorespiratory fitness, such data rarely become available or are not used by public health and clinical practitioners for purposes of health promotion or disease prevention.[29] Physicians have access to measures

Table 3 Twenty meter shuttle run stages that need to be met to fall within the healthy cardiorespiratory fitness level by age and gender

Age (years)	Boys				Girls			
	Lower stage (41.8 mL/kg/min)	Speed (km/hour)	Upper stage (47.0 mL/kg/min)	Speed (km/hour)	Lower stage (34.6 mL/kg/min)	Speed (km/hour)	Upper stage (39.5 mL/kg/min)	Speed (km/hour)
8	1	8.5	3	9.5	1	8.5	1	8.5
9	2	9	4	10	1	8.5	1	8.5
10	2	9	5	10.5	1	8.5	1	8.5
11	3	9.5	5	10.5	1	8.5	2	9
12	4	10	6	11	1	8.5	3	9.5
13	5	10.5	7	11.5	2	9	4	10
14	5	10.5	7	11.5	2	9	4	10
15	6	11	8	12	3	9.5	5	10.5
16	6	11	8	12	4	10	6	11
17	7	11.5	9	12.5	4	10	6	11
18	7	11.5	9	12.5	5	10.5	7	11.5

Estimations are made using the equation reported by Leger et al.[32]

of cardiovascular disease risk factors such as fasting blood samples and blood pressure; however, some of these procedures are invasive, expensive and not suitable for cardiovascular disease risk screening among large populations of children and adolescents and at school settings. The origins of cardiovascular disease are found in childhood,[1] and low cardiorespiratory fitness levels at childhood and adolescence are associated with cardiovascular disease risk during these years and later in life;[10 11] thus, lifestyle modification focused on enhancing physical activity and increasing fitness might help improving their cardiovascular health.

Strengths and limitations
The findings from the present study support the cross-cultural generalisability of the cardiorespiratory fitness standards in children and adolescents, but there are some limitations of this meta-analysis that should be considered. Some of them are common to meta-analyses (eg, publication bias, selection bias and limited information from study reports). Even though we did not find evidence of significant publication bias, this does not completely exclude this possibility. The results showed substantial level of heterogeneity, thus should be interpreted with caution. The total number of studies in our analyses was relatively small; however, this may be offset by the inclusion of a relatively large number of children and adolescents (n=9280). In addition, available studies are restricted to 14 countries including a representative sample of USA, as well as countries from Europe with diverse environmental, cultural and social factors. It would be desirable to have data from other geographical locations to make the results generalisable to all populations around the globe. Unfortunately, there are not enough studies to conduct analyses by age group, nevertheless we have conducted a sensitivity analysis excluding studies that included children aged under 12 years, and the estimations did not change substantially. VO_{2max} associated with a healthier cardiovascular profile ranged from 43.8 to 47.0 mL/kg/min in boys and from 33.0 to 36.0 mL/kg/min in girls older than 12 years.

Next steps
On the basis of our meta-analysis, we suggest four steps.
1. Development of a cardiovascular prediction algorithm in paediatric populations (eg, International Diabetes Federation) that consider cardiorespiratory fitness and the traditional cardiovascular disease risk factors to allow paediatricians to use

cardiorespiratory fitness as a way of stratifying risk in clinical settings. Currently, the International Diabetes Federation does not even include cardiorespiratory fitness in the definition of metabolic syndrome, which might be interpreted that fitness is not an important parameter of metabolic health. The present study suggests otherwise and provides health-related cut points that could be used;
2. Evaluation of feasibility of exercise testing for assessing cardiorespiratory fitness in the schools, sport clubs[56] or clinical settings from the viewpoint of primary prevention of cardiovascular disease;
3. Long-term longitudinal studies testing whether children and adolescents meeting the cardiorespiratory fitness cut points have a better cardiovascular health later in life, and lower risk of developing cardiovascular disease;
4. A clinical trial to determine whether an exercise-based intervention that improves cardiorespiratory fitness also improves the cardiovascular profile and prevents future cardiovascular disease, including metabolic syndrome, type 2 diabetes, obesity or hypertension.

CONCLUSIONS
Our meta-analysis suggests that cardiorespiratory fitness, which can be easily assessed by a field-based exercise test (ie, the 20 m shuttle run test), can be used as a marker of cardiovascular health in children and adolescents. On the basis of the results presented here, fitness levels below 42 and 35 mL/kg/min for boys and girls, respectively, should raise a red flag. The consistency of findings reported in the present study provide strong evidence to support the broader adoption of cardiorespiratory fitness standards for use in schools and sport programmes as well as in clinical settings as part of surveillance and/or screening systems to identify children and adolescents with cardiovascular disease risk who might benefit from intervention programmes.

What are the findings?

▶ Cardiorespiratory fitness is a marker of cardiovascular health in children and adolescents.
▶ Cardiorespiratory fitness cut points to avoid cardiovascular disease risk range between 41.8 and 47.0 mL/kg/min in boys and between 34.6 and 39.5 mL/kg/min in girls.

Review

REFERENCES

1 Berenson GS, Srinivasan SR, Bao W, et al. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. The Bogalusa Heart Study. N Engl J Med 1998;338:1650–6.
2 Mahoney LT, Burns TL, Stanford W, et al. Coronary risk factors measured in childhood and young adult life are associated with coronary artery calcification in young adults: the Muscatine study. J Am Coll Cardiol 1996;27:277–84.
3 Raitakari OT, Juonala M, Kähönen M, et al. Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: the Cardiovascular Risk in Young Finns Study. JAMA 2003;290:2277–83.
4 Cook S, Weitzman M, Auinger P, et al. Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third national health and nutrition examination survey, 1988–1994. Arch Pediatr Adolesc Med 2003;157:821–7.
5 Cruz ML, Goran MI. The metabolic syndrome in children and adolescents. Curr Diab Rep 2004;4:53–62.
6 de Ferranti SD, Gauvreau K, Ludwig DS, et al. Prevalence of the metabolic syndrome in American adolescents: findings from the third National Health and Nutrition Examination Survey. Circulation 2004;110:2494–7.
7 Viner RM, Segal TY, Lichtarowicz-Krynska E, et al. Prevalence of the insulin resistance syndrome in obesity. Arch Dis Child 2005;90:10–14.
8 Zimmet P, Alberti KG, Kaufman F, et al. The metabolic syndrome in children and adolescents—an IDF consensus report. Pediatr Diabetes 2007;8:299–306.
9 Taylor HL, Buskirk E, Henschel A. Maximal oxygen intake as an objective measure of cardio-respiratory performance. J Appl Physiol 1955;8:73–80.
10 Ortega FB, Ruiz JR, Castillo MJ, et al. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond) 2008;32:1–11.
11 Ruiz JR, Castro-Piñero J, Artero EG, et al. Predictive validity of health-related fitness in youth: a systematic review. Br J Sports Med 2009;43:909–23.
12 Högström G, Nordström A, Nordström P. High aerobic fitness in late adolescence is associated with a reduced risk of myocardial infarction later in life: a nationwide cohort study in men. Eur Heart J 2014;35:3133–40.
13 Ortega FB, Ruiz JR, Labayen I, et al. Role of socio-cultural factors on changes in fitness and adiposity in youth: a 6-year follow-up study. Nutr Metab Cardiovasc Dis 2013;23:883–90.
14 Castro-Piñero J, Artero EG, España-Romero V, et al. Criterion-related validity of field-based fitness tests in youth: a systematic review. Br J Sports Med 2010;44:934–43.
15 Ruiz JR, Castro-Piñero J, España-Romero V, et al. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. Br J Sports Med 2011;45:518–24.
16 Ortega FB, Cadenas-Sanchez C, Sanchez-Delgado G, et al. Systematic review and proposal of a field-based physical fitness-test battery in preschool children: the PREFIT battery. Sports Med 2015;45:533–55.
17 Welk GJ, Laurson KR, Eisenmann JC, et al. Development of youth aerobic-capacity standards using receiver operating characteristic curves. Am J Prev Med 2011;41:S111–16.
18 Cole TJ, Bellizzi MC, Flegal KM, et al. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000;320:1240–3.
19 Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis of observational studies in epidemiology (moose) group. JAMA 2000;283:2008–12.
20 Macaskill P, Gatsonis C, Deeks JJ, et al. Cochrane handbook for systematic reviews of diagnostic test accuracy. Version 09 0. London: The Cochrane Collaboration, 2010.
21 Whiting PF, Rutjes AW, Westwood ME, et al. Quadas-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med 2011;155:529–36.
22 Glas AS, Lijmer JG, Prins MH, et al. The diagnostic odds ratio: a single indicator of test performance. J Clin Epidemiol 2003;56:1129–35.
23 Jones CM, Athanasiou T. Summary receiver operating characteristic curve analysis techniques in the evaluation of diagnostic tests. Ann Thorac Surg 2005;79:16–20.
24 Deeks JJ, Macaskill P, Irwig L. The performance of tests of publication bias and other sample size effects in systematic reviews of diagnostic test accuracy was assessed. J Clin Epidemiol 2005;58:882–93.
25 Reitsma JB, Glas AS, Rutjes AW, et al. Bivariate analysis of sensitivity and specificity produces informative summary measures in diagnostic reviews. J Clin Epidemiol 2005;58:982–90.
26 Ruiz JR, Huybrechts I, Cuenca-García M, et al. Cardiorespiratory fitness and ideal cardiovascular health in European adolescents. Heart 2015;101:766–73.
27 Ruiz JR, Ortega FB, Rizzo NS, et al. High cardiovascular fitness is associated with low metabolic risk score in children: the European Youth Heart Study. Pediatr Res 2007;61:350–5.
28 Mesa JL, Ruiz JR, Ortega FB, et al. Aerobic physical fitness in relation to blood lipids and fasting glycaemia in adolescents: influence of weight status. Nutr Metab Cardiovasc Dis 2006;16:285–93.
29 Lobelo F, Pate RR, Dowda M, et al. Validity of cardiorespiratory fitness criterion-referenced standards for adolescents. Med Sci Sports Exerc 2009;41:1222–9.
30 Adegboye AR, Anderssen SA, Froberg K, et al. Recommended aerobic fitness level for metabolic health in children and adolescents: a study of diagnostic accuracy. Br J Sports Med 2011;45:722–8.
31 Moreira C, Santos R, Ruiz JR, et al. Comparison of different VO(2max) equations in the ability to discriminate the metabolic risk in Portuguese adolescents. J Sci Med Sport 2011;14:79–84.
32 Leger LA, Mercier D, Gadoury C, et al. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci 1988;6:93–101.
33 Hansen HS, Froberg K, Nielsen JR, et al. A new approach to assessing maximal aerobic power in children: The Odense School Child Study. Eur J Appl Physiol Occup Physiol 1989;58:618–24.
34 Pate RR, Wang CY, Dowda M, et al. Cardiorespiratory fitness levels among us youth 12 to 19 years of age: findings from the 1999–2002 National Health and Nutrition Examination Survey. Arch Pediatr Adolesc Med 2006;160:1005–12.
35 Matsuzaka A, Takahashi Y, Yamazoe M, et al. Validity of the multistage 20-m shuttle-run test for Japanese children, adolescents, and adults. Ped Exerc Sci 2004;16:113–25.
36 Lloyd-Jones DM, Hong Y, Labarthe D, et al. Defining and setting national goals for cardiovascular health promotion and disease reduction: the American Heart Association's strategic Impact Goal through 2020 and beyond. Circulation 2010;121:586–613.
37 España-Romero V, Artero EG, Jimenez-Pavón D, et al. Assessing health-related fitness tests in the school setting: reliability, feasibility and safety; the ALPHA study. Int J Sports Med 2010;31:490–7.
38 Cadenas-Sanchez C, Alcantara-Moral F, Sanchez-Delgado G, et al. [Assessment of cardiorespiratory fitness in preschool children: adaptation of the 20 metres shuttle run test]. Nutr Hosp 2014;30:1333–43.
39 Cadenas-Sanchez C, Martinez-Tellez B, Sanchez-Delgado G, et al. Assessing physical fitness in preschool children: feasibility, reliability and practical recommendations for the PREFIT battery. J Sci Med Sport 2016.
40 The Cooper Institute for Aerobics Research. Fitnessgram test administration manual. Champaign, IL: Human kinetics, 1999:38–9.
41 Laurson KR, Saint-Maurice PF, Karsai I, et al. Cross-validation of FITNESSGRAM® health-related fitness standards in Hungarian youth. Res Q Exerc Sport 2015;86 (Suppl 1):S13–20.
42 Olds T, Tomkinson G, Leger L, et al. Worldwide variation in the performance of children and adolescents: an analysis of 109 studies of the 20-m shuttle run test in 37 countries. J Sports Sci 2006;24:1025–38.
43 Tomkinson GR, Lang JJ, Tremblay MS, et al. International normative 20 m shuttle run values from 1 142 026 children and youth representing 50 countries. Br J Sports Med Published Online First: 20 May 2016 doi:10.1136/bjsports-2016-095987.
44 Artero EG, Espana-Romero V, Castro-Pinero J, et al. Reliability of field-based fitness tests in youth. Int J Sports Med 2011;32:159–69.
45 Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. Nat Rev Neurosci 2008;9:58–65.
46 Carnethon MR, Gidding SS, Nehgme R, et al. Cardiorespiratory fitness in young adulthood and the development of cardiovascular disease risk factors. JAMA 2003;290:3092–100.
47 Boreham CA, Ferreira I, Twisk JW, et al. Cardiorespiratory fitness, physical activity, and arterial stiffness: the Northern Ireland Young Hearts Project. Hypertension 2004;44:721–6.
48 Ferreira I, Twisk JW, Stehouwer CD, et al. Longitudinal changes in .VO2max: associations with carotid IMT and arterial stiffness. Med Sci Sports Exerc 2003;35:1670–8.
49 Bugge A, El-Naaman B, McMurray RG, et al. Tracking of clustered cardiovascular disease risk factors from childhood to adolescence. Pediatr Res 2013;73:245–9.
50 Kristensen PL, Wedderkopp N, Moller NC, et al. Tracking and prevalence of cardiovascular disease risk factors across socio-economic classes: a longitudinal substudy of the European Youth Heart study. BMC Public Health 2006;6:20.

51 Andersen LB, Haraldsdottir J. Tracking of cardiovascular disease risk factors including maximal oxygen uptake and physical activity from late teenage to adulthood. An 8-year follow-up study. *J Intern Med* 1993;234:309–15.

52 McKay HA, Macdonald HM, Nettlefold L, *et al*. Action schools! Bc implementation: from efficacy to effectiveness to scale-up. *Br J Sports Med* 2015;49:210–18.

53 Bangsbo J, Krustrup P, Duda J, *et al*. The Copenhagen Consensus Conference 2016: children, youth, and physical activity in schools and during leisure time. *Br J Sports Med* 2016;50:1177–8.

54 McDonald SM, Trost SG. The effects of a goal setting intervention on aerobic fitness in middle school students. *J Teach Phys Educ* 2015;34:576–87.

55 Bai Y, Saint-Maurice PF, Welk GJ, *et al*. Prevalence of Youth Fitness in the United States: baseline results from the NFL PLAY 60 FITNESSGRAM Partnership Project. *J Pediatr* 2015;167:662–8.

56 Bergeron MF, Mountjoy M, Armstrong N, *et al*. International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;49:843–51.

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Cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents; what level of fitness should raise a red flag? A systematic review and meta-analysis

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