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Predictive validity of health-related fitness in youth: a systematic review

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ABSTRACT

The objective of the present systematic review was to investigate whether physical fitness in childhood and adolescence is a predictor of cardiovascular disease (CVD) risk factors, events and syndromes, quality of life and low back pain later in life. Physical fitness-related components were: cardiorespiratory fitness, musculoskeletal fitness, motor fitness and body composition. Adiposity was considered as both exposure and outcome. The results of 42 studies reporting the predictive validity of health-related physical fitness for CVD risk factors, events and syndromes as well as the results of five studies reporting the predictive validity of physical fitness for low back pain in children and adolescents were summarised. Strong evidence was found indicating that higher levels of cardiorespiratory fitness in childhood and adolescence are associated with a healthier cardiovascular profile later in life. Muscular strength improvements from childhood to adolescence are negatively associated with changes in overall adiposity. A healthier body composition in childhood and adolescence is associated with a healthier cardiovascular profile later in life and with a lower risk of death. The evidence was moderate for the association between changes in cardiorespiratory fitness and CVD risk factors, and between cardiorespiratory fitness and the risk of developing the metabolic syndrome and arterial stiffness. Moderate evidence on the lack of a relationship between body composition and low back pain was found. Due to a limited number of studies, inconclusive evidence emerged for a relationship between muscular strength or motor fitness and CVD risk factors, and between flexibility and low back pain.

Cardiovascular disease (CVD) is the leading cause of global mortality.[1] CVD events occur most frequently during or after the fifth decade of life; however, there is evidence indicating that the precursors of CVD have their origin in childhood and adolescence.[2 3] Adverse CVD risk factors during childhood seem to track into adulthood.[4 5] The most recognised CVD risk factors are obesity, high levels of triglycerides and blood cholesterol, insulin resistance, inflammatory proteins, high blood pressure, physical inactivity and low physical fitness.

Musculoskeletal problems and conditions are common and have important consequences for both the individual and society. Approximately 50% of the population report musculoskeletal pain at one or more sites in the past month,[6] and the figures for young people are similar.[6] Population surveys reported that back pain is the most common site of regional pain in young people and middle-aged adults. In adolescents, the lifetime prevalence of low back pain ranges from 7% to 72%.[6]

Quality of life refers to the degree of wellbeing felt by an individual or group of people. Quality of life has a physical component that includes aspects such as health, diet, as well as protection against pain and disease. It also has a psychological component that includes aspects related to stress, worries, pleasure and other positive or negative emotional states. Several cross-sectional studies have reported an association between fitness and wellbeing in youth.[7–10]

Whether physical fitness is an important marker of health already in childhood and adolescence is still under debate,[11–13] because most of the evidence comes from cross-sectional studies. In the past few decades, several longitudinal studies in children and adolescents reported on the relationship between physical fitness-related exposures and the risk of developing an unhealthy cardiovascular or musculoskeletal profile later in life. Understanding whether low/high physical fitness in young people is a predictor of future disease/better health status would clarify the debate as to whether physical fitness should or should not be assessed in health monitoring systems.

The objective of the present systematic review was to investigate whether physical fitness in childhood and adolescence is a predictor of CVD risk factors, type 2 diabetes, metabolic syndrome and cardiovascular events later in life. We also examined whether there is evidence that physical fitness in childhood and adolescence is a predictor of quality of life and low back pain later in life.

METHODS

The present systematic review is produced as a part of the ALPHA (instruments for Assessing Levels of PHysical Activity and fitness) study. The ALPHA study aims to provide a set of instruments for assessing levels of physical activity as well as health-related physical fitness in a comparable way within the European Union.

Selected health outcomes

Based on recent knowledge of major health problems and their risk factors, several health outcomes were selected to seek evidence for associations between physical fitness and health status in children and adolescents.

The main question was ‘‘does low/high fitness in youth predict future disease/better health status? We selected longitudinal cohort studies examining the association between physical fitness in children and adolescents and future: (1) CVD risk factors: blood lipids, blood pressure, insulin sensitivity, inflammatory markers and overall and central adiposity; (2) CVD/syndromes: obesity, hypertension, dyslipidaemia, diabetes and the metabolic syndrome; (3) low back pain; (4) quality of life and wellbeing, also called positive health outcomes: school performance, self-esteem, mood status, socialisation, resilience (ie, the positive capacity of people to cope with stress) and risk-avoidance behaviour.

The health-related fitness components and factors/traits are depicted in fig 1.[14] Definitions of the concepts used in the manuscript can be seen in the supplemental material (available online only).

Procedures

The electronic databases MEDLINE, EMBASE, SCOPUS and SPORTS DISCUS were screened for longitudinal studies (either prospective or retrospective cohort studies) in children and adolescents in which one or more fitness tests were carried out, and the outcome measured was one of the selected health outcomes.

The key words used (in various combination) were: physical fitness, fitness, aerobic capacity, maximum oxygen consumption, cardiorespiratory fitness, cardiovascular fitness, strength, flexibility, motor, endurance, speed, agility, balance, body composition, anthropometry, body mass index (BMI), waist circumference, overall adiposity, central adiposity, overweight, obesity, risk factors, risk score CVD, metabolic syndrome, blood glucose, glucose tolerance, insulin resistance, insulin sensitivity, blood lipids, dyslipidaemia, diabetes, blood pressure, hypertension, inflammatory markers, bone mineral density, bone mineral content, school performance, self-esteem, mood status, socialisation, resilience, risk avoidance behaviour, mental health and low back pain.

Search limits were: papers published from January 1990 to July 2008, written in English, in "humans" and "all child" (0–18 years). An additional search using adolescents (13–18 years) was also performed. There were no exclusion criteria with regard to ethnic origin. Additional studies were indentified from reference lists.

The abstracts of longitudinal studies proposed to be included in the review were checked for the following criteria: (1) the study was a full report published in a peer-reviewed journal; (2) the study design was a longitudinal study; (3) the study population was a healthy community-based population; (4) one or more fitness tests were carried out; (5) the outcome measure was one of the selected health outcomes. Articles were included if they met all these five criteria. Two independent reviewers (JRR, JCP) read all the abstracts, and a consensus meeting was arranged to sort out differences between both of them.

The results of the most recent reviews were summarised first, and then the studies potentially relevant for the selected topics were screened for retrieval. Finally, a snowball search was done, in which reference lists of the selected articles were checked for titles including physical fitness and selected health outcomes.

Quality assessment

The quality of the selected studies was scored using a quality assessment list for longitudinal studies.[15] The list included five items on population, designs, methods and report of the results. The items on the list were rated as "1" (positive), "0" (negative) or "?" (unclear), see table 1. For all studies, a total quality score was calculated by counting up the number of positive items (a total score between 0 and 5). Studies were defined as high quality if they had a total score of 3 or higher. A total score of 2 was defined as low quality, and a score of less than 2 was defined as very low quality. Two reviewers (JRR and JCP) separately evaluated the quality of the studies. A consensus meeting was arranged to sort out differences between both

Table 1 Quality assessment list for prospective cohort studies

Was the selection of the population non-selective with respect to a healthy or physical functioning?	1 = yes 0 = no ? = unclear
Were the selected health outcomes clearly described?	1 = yes 0 = no ? = unclear
The time between the measurement of physical fitness and the health outcome was at least 1 year	1 = yes, >1 year 0 = no, ⩽1 year ? = unclear
Were the results adjusted for confounders?	1 = yes 0 = no ? = unclear
Were standard errors and/or confidence intervals given for the estimates or was information given to calculate these?	1 = yes 0 = no ? = unclear

Rating for total score: high quality, 3–5; low quality, 2; very low quality, 1.

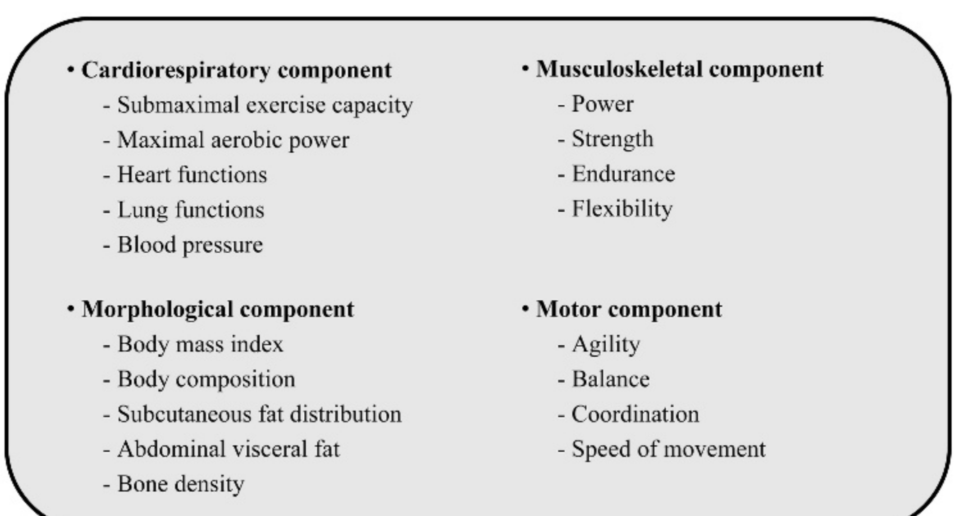

Figure 1 Health-related fitness components and factors/traits. Modified from Bouchard *et al*[14] with permission.

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reviewers. The articles were not blinded for authors, institution and journal, because the reviewers who performed the quality assessment were familiar with the literature.

Levels of evidence

Three levels of evidence were constructed:[16] (1) strong evidence: consistent findings in three or more high-quality studies; (2) moderate evidence: consistent findings in two high-quality studies; (3) limited or conflicting evidence: consistent findings in multiple low-quality studies, inconsistent results found in multiple high-quality studies, or results based on one single study.

Data extraction

Information on design, statistical procedures, population characteristics, years of follow-up, fitness tests, outcome and risk estimates and main results was extracted from all studies. Data extraction was separated for CVD risk factors, low back pain and for quality of life. We regarded results with a $p \leqslant 0.05$ as statistically significant.

RESULTS

Health-related physical fitness predictive validity for CVD risk factors and disease

A total of 42 longitudinal studies was included (table 2). Cardiorespiratory fitness was assessed in 20 (48%) studies,

Table 2 List of included longitudinal studies with quality scores with reference to predictive value of physical fitness for CVD risk factors and disease in children and adolescents

Study	Fitness dimension	Selection of population	Description of outcome	Follow-up time	Confounder adjustment	Risk estimates	Total score
Low-quality studies							
Eisenmann *et al*[49]	Cardiorespiratory fitness and body composition	0	1	1	0	0	2
McGavock *et al*[37]	Cardiorespiratory fitness and body composition	1	1	0	0	0	2
Monyeki *et al*[38]	Cardiorespiratory, motor and musculoskeletal fitness	1	1	0	0	0	2
Raitakari *et al*[50]	Body composition	1	0	1	0	0	2
High-quality studies							
Andersen *et al*[20]	Cardiorespiratory fitness	1	1	1	0	0	3
Hasselstrom *et al*[18]	Cardiorespiratory and musculoskeletal fitness	1	1	1	0	0	3
Psarra *et al*[21]	Cardiorespiratory fitness and body composition	1	1	0	0	1	3
Twisk *et al*[19]	Cardiorespiratory fitness	1	1	1	0	0	3
Srinivasan *et al*[22]	Body composition	1	1	1	0	0	3
Barnekow-Bergkvist *et al*[23]	Cardiorespiratory and musculoskeletal fitness	1	1	1	0	1	4
Boreham *et al*[26]	Cardiorespiratory fitness	1	1	1	1	0	4
Garnett *et al*[39]	Body composition	1	1	1	0	1	4
Janz *et al*[25]	Cardiorespiratory and musculoskeletal fitness	1	1	1	1	0	4
Johnson *et al*[24]	Cardiorespiratory fitness	1	1	1	1	0	4
McMurray *et al*[27]	Cardiorespiratory fitness	1	1	1	0	1	4
Pietilainen *et al*[17]	Self-perceived physical fitness	1	1	1	0	1	4
Carnethon *et al*[30]	Cardiorespiratory fitness	1	1	1	1	1	5
Boreham *et al*[29]	Cardiorespiratory fitness	1	1	1	1	1	5
Byrd-Williams *et al*[34]	Cardiorespiratory fitness	1	1	1	1	1	5
Ferreira *et al*[31]	Cardiorespiratory fitness	1	1	1	1	1	5
Ferreira *et al*[33]	Cardiorespiratory fitness and body composition	1	1	1	1	1	5
Koutedakis *et al*[32]	Cardiorespiratory fitness	1	1	0	1	1	5
Twisk *et al*[28]	Cardiorespiratory, motor and musculoskeletal fitness	1	1	1	1	1	5
Baker *et al*[44]	Body composition	1	1	1	1	1	5
Bjorge *et al*[53]	Body composition	1	1	1	1	1	5
Engeland *et al*[54]	Body composition	1	1	1	1	1	5
Franks *et al*[48]	Body composition	1	1	1	1	1	5
Gunnell *et al*[51]	Body composition	1	1	1	1	1	5
Juonala *et al*[40]	Body composition	1	1	1	1	1	5
Juonala *et al*[41]	Body composition	1	1	1	1	1	5
Lawlor and Leon[45]	Body composition	1	1	1	1	1	5
Lawlor *et al*[46]	Body composition	1	1	1	1	1	5
Must *et al*[52]	Body composition	1	1	1	1	1	5
Oren *et al*[47]	Body composition	1	1	1	1	1	5
Raitakari *et al*[4]	Body composition	1	1	1	1	1	5
Sivanandam *et al*[43]	Body composition	1	1	1	1	1	5
van Lenthe *et al*[42]	Body composition	1	1	1	1	1	5

Table 3 Longitudinal studies on predictive validity of physical fitness for CVD risk factors and disease in children and adolescents

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Low-quality studies							
Cardiorespiratory fitness and body composition	Eisenmann *et al*[49] The Aerobics Center Longitudinal Study Quality score 2	~11	Boys 36 Girls 12	15.9 to 27.2	Maximal treadmill test using the modified Balke protocol (expressed as duration of the treadmill test), BMI, WC and BF (estimated using equations)	TG, TC, HDLc, glucose and BP	Boys and girls Adolescent CRF and ΔCRF showed moderate negative correlations with adult BF indicators (BMI, WC and %BF, r = −0.34 to −0.47) and ΔBF (r = −0.24 to −0.46), respectively. Adolescent CRF was not significantly related to CVD risk factors in adulthood. Adolescent WC was positively related to adult BP (r = 0.33–0.45), and BF variables during adolescence were negatively related to adult CRF (r = −0.32 to −0.44). The ΔWC was negatively related to ΔCRF (r = −0.46) and ΔHDLc (r = −0.51), and ΔBMI was negatively related to ΔBP (r = 0.45) and ΔHDLc (r = −0.34)
Cardiorespiratory fitness and body composition	McGavock *et al*[37] Quality score 2	2 2004–6	2089	5–19 to 7–21	20 mSRT (estimated Vo_{2max} expressed as ml/kg/min) and weight	BP, large-artery compliance and systemic vascular resistance	Boys and girls Weight gain and changes in heart rate and stroke volume were independently associated with changes in SBP over time. Specifically, SBP increased 0.77 mm Hg for every kilogram of weight gain over the 2-year follow-up. CRF was not a significant predictor of the baseline or age-related change in SBP
Cardiorespiratory, motor and musculoskeletal fitness	Monyeki *et al*[38] The Ellisras Longitudinal Study Quality score 2	1 2001–2	Boys 380 Girls 322	7–14 to 8–15	1600 m run, standing broad jump, bent arm hang, sit-ups, 4×5 m shuttle run and 50 m run	BMI, FFM, sum of four skinfolds, BF estimated with equations, arm muscle area, SS/SSF	Boys and girls The changes in weight/age, BMI, sum of skinfolds, FFM and SS/SSF were inversely related with bent arm hang in the pre-adolescent and adolescent boys and girls. Changes in BMI were negatively associated with sit-ups in girls. Changes in height/age, weight/age, BMI, sum of skinfolds, BF and arm muscle area showed negative relationships with changes in shuttle run, 1600 m run and 50 m run
Body composition	Raitakari *et al*[50] Cardiovascular Risk in Young Finns Study Quality score 2	21 1980 2001–2	3596 2283	3–18 to 24–39	BMI, skinfold thickness	Insulin, glucose, blood pressure, carotid artery IMT and carotid artery elasticity	Boys and girls BMI was positively associated with adult IMT ($p<0.05$). However, when adulthood BMI was entered into the model, the effect of childhood BMI became non-significant. The age and sex-adjusted multivariate correlates of carotid artery elasticity included childhood skinfold thickness (sum of biceps, triceps and subscapular; $p<0.05$). However, the effect of childhood skinfold thickness on carotid artery elasticity became non-significant ($p = 0.16$) when adjusted with adult BMI
High-quality studies							
Cardiorespiratory fitness	Andersen *et al*[20] Danish Youth and Sport Study Quality score 3	8 1983–91	Boys 133 Girls 172 Boys 98 Girls 137	16–19 to 24–27	Maximal cycle ergometer test (measured Vo_{2max} expressed as l/min and l/kg/min)	TG, TC/HDLc, SBP, BF derived from skinfolds. The upper quartile was defined as being at risk. If the subject has two or more risk factors, she/he was defined as "a case"	Boys and girls ORs for having two or more risk factors between quartiles of CRF were 3.1, 3.8 and 4.9 for quartiles two to four, respectively. At the second examination, OR were 0.7, 3.5 and 4.9, respectively. The probability for "a case" at the first examination to be "a case" at the second was 6.0
Cardiorespiratory and musculoskeletal fitness	Hasselstrom *et al*[18] Danish Youth and Sports Study Quality score 3	8 1983–91	Boys 133 Girls 132 Boys 45 Girls 57	15–19 to 23–27	Maximal cycle ergometer test (measured Vo_{2max} expressed as ml/kg/min). Isometric muscular strength index (calculated as the sum of the scores obtained in elbow flexors, knee extensors, trunk flexors and truck extensors relative to body weight)	TG, HDLc, BP, %BF and risk score (calculated as the sum of the measured outcomes)	Boys CRF changes were negatively correlated with the changes in TC, TG, HDLc/TC ($p<0.05$). Muscular strength changes were negatively correlated with the changes in WC and %BF ($p<0.05$). Girls CRF changes were negatively correlated with the changes in TG, SBP, %BF and risk score ($p<0.05$). Muscular strength was not associated with any of the outcome measures in girls

Continued

Table 3 Continued

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Cardiorespiratory fitness	Psarra *et al*[21] Quality score 3	2 2000–1, 2002–3	Boys 477 Girls 441	6–12 to 8–14	20 mSRT (no of completed laps)	BMI, WC, W/H and %BF estimated using an electronic body composition analyser (Tanita)	Boys and girls BMI at the baseline, parental obesity and low level of CRF were the main predictors of the 2-year tracking of BF. WC and CRF level were the only significant predictors of high WC after 2 years
Cardiorespiratory, musculoskeletal and motor fitness	Twisk *et al*[19] The Amsterdam Growth and Health Longitudinal Study Quality score 3	15 1977–91	181	13 to 27	Maximal treadmill test (measured Vo_{2max} expressed as ml/min/kg$^{2/3}$). Neuromotor fitness index (muscle strength, speed of movement, and coordination)	TC, HDLc, TC/HDLc, SBP, DBP, sum of four skinfolds and W/H	Boys and girls CRF was negatively related to TC, TC/HDL ratio and the sum of four skinfolds. Neuromotor fitness was positively related to SBP and DBP and inversely to the sum of four skinfolds ($p<0.05$)
Body composition	Srinivasan *et al*[22] The Bogalusa Heart Study Quality score 3	14	783	13–17 to 27–31	BMI, subscapular and triceps skinfolds	TG, TC, HDLc, TC/HDLc, LDLc, BP, insulin and glucose	Boys and girls As young adults, the overweight individuals showed adverse levels of body fatness measures, SBP and DBP, lipid profile, insulin and glucose as compared with the lean individuals ($p<0.01$ to <0.001). The prevalence of clinically recognised hypertension and dyslipidaemia increased 8.5-fold and 3.1-fold to 8.3-fold, respectively, in the overweight individuals versus the lean individuals ($p<0.05$). Clustering of adverse values (>75th percentile) for the TC/HDLc, insulin level and SBP occurred only among the overweight individuals ($p<0.001$)
Cardiorespiratory and musculoskeletal fitness	Barnekow-Bergkvist *et al*[23] Quality score 4	18 1974–92	Boys 220 Girls 205 Boys 157 Girls 121	15–18 to 33–36	1974: Run-walk test (score: distance covered in nine minutes) 1992: Submaximal cycle ergometer test (estimated Vo_{2max} expressed as ml/kg/min) Muscular strength: no of sit-ups and no of lifts in the bench-press test. Maximal static lifting strength was measured with the two-hand lift test	BMI, WC, W/H, TC, HDLc and SBP	Boys and girls CRF at the age of 16 years was not associated with any of the outcomes measures at the age of 34 years. Bench-press was negatively associated with BMI in boys/men, whereas two-hand lift was negatively associated with BMI in girls/women
Cardiorespiratory fitness	Boreham *et al*[26] The Northern Ireland Young Hearts Project Quality score 4	8	Boys 251 Girls 203	12–15 to 20–25	Submaximal cycle ergometer test (estimated Vo_{2max} by extrapolation of Vo_2 at 170 bpm to the age-adjusted estimated maximal heart rate, and expressed as ml/kg/min)	Arterial stiffness	Boys and girls CRF was inversely and significantly associated with pulse wave velocity of both the elastic aortoiliac segment and the muscular aortodorsalis pedis segment. These associations were only slightly stronger with the muscular segment and were independent of (ie, not confounded nor mediated by) lifestyle variables, BF and physical activity
Body composition	Garnett *et al*[39] Quality score 4	7	342 290	7 to 14	BMI and WC	CVD risk clustering	Boys and girls Children who were overweight or obese at 8 years of age were 7 times (OR 6.9; 95% CI 2.5 to 19.0; $p<0.001$) as likely to have CVD risk clustering in adolescence than were their peers who were not overweight or obese. Those with an increased WC at 8 years were four times (95% CI 3.6; 1.0 to 12.9; $p = 0.061$) as likely to have CVD risk clustering in adolescence than were children with a smaller WC. Neither BMI nor WC were predictive of CVD risk clustering if adiposity was not included as a risk factor
Cardiorespiratory and musculoskeletal fitness	Janz *et al*[25] The Muscatine Study Quality score 4	5	Boys 63 Girls 62	10.5 to 15	Maximal cycle ergometer test (measured Vo_{2max} expressed as ml/min/kg$^{2/3}$). Maximum handgrip strength test (sum of right and left hand)	TC, HCLc, TC/HDLc, LDLc, sum of six skinfolds, WC and BP	Boys and girls CRF changes were negatively correlated with changes in TC/HDLc, LDLc, sum of six skinfolds and WC ($p<0.05$) after controlling for age, gender, FFM and pubertal status. Muscular strength changes were negatively correlated with changes in SBP, sum of six skinfolds and WC ($p<0.05$) after controlling for age, gender, FFM and pubertal status

Continued

Table 3 Continued

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Cardiorespiratory fitness	Johnson *et al*[24] Quality score 4	3–5	White boys 17 White girls 55 Black boys 19 Black girls 24	4.6–11 to 8–16	Progressive walking treadmill test (measured Vo_{2max} expressed as l/min)	BF and lean tissue mass measured by DXA	Boys and girls CRF was negatively associated with increased adiposity. Children with a higher CRF at the start of the study had a lower rate of increase of adiposity over the course of the study
Cardiorespiratory fitness	McMurray *et al*[27] Quality score 4	7 1990–6	Boys 212 Girls 177	7–10 to 14–17	Submaximal cycle ergometry test (estimated Vo_{2max} expressed as ml/min/kg^{FFM})	BMI, BP, BF estimated from triceps and subscapular skinfolds, blood lipids, metabolic syndrome	Boys and girls Children with low (first third) CRF (ml/kg/min) were 5.5–6 times more likely to have metabolic syndrome as an adolescent. When childhood CRF was expressed in terms of ml/kg^{FFM}/min, the OR for metabolic syndrome during adolescence comparing the low versus high Vo_{2max} was not significant ($p<0.07$); however, when the low CRF (mL/kg^{FFM}/min) was compared with the moderate (second third), the OR was significant ($p<0.03$)
Self-perceived physical fitness	Pietilainen *et al*[17] Quality score 4	4 1975–9	4840 (including 1870 twins pairs)	16–18 to 22–27	Self-perceived physical fitness. Alternatives were "very good, fairly good, satisfactory, rather poor, very poor". The two first and two last alternatives were combined to yield good, satisfactory and poor fitness classes	BMI, WC, BF, FFM, %BF assessed by DXA	Boys and girls Those who perceived themselves as persistently unfit in adolescence had a marked risk of adult overall (5.1; 95% CI 2.0 to 12.7) and abdominal obesity (3.2; 95% CI 1.5 to 6.7). Adult obesity risk was also increased in those whose fitness declined from 16 to 18 years
Cardiorespiratory fitness	Carnethon *et al*[30] Coronary Artery Risk Development in Young Adults Quality score 5	15 1985–6 1992–3 2000–1	Men 2029 Women 2458 2478 3550	18–30 to 43–45	Maximal treadmill test according to a modified Balke protocol (expressed as duration of the treadmill test)	Incidence of type 2 diabetes, hypertension, the metabolic syndrome and hypercholesterolaemia	Boys and girls Participants with low CRF (<20th percentile) were 3 to 6-fold more likely to develop diabetes, hypertension and the metabolic syndrome than participants with high CRF (⩾60th percentile; all $p<0.001$). Adjusting for baseline BMI diminished the strength of these associations to 2-fold (all $p<0.001$). In contrast, the association between low CRF and hypercholesterolaemia was modest (HR 1.4; 95% CI 1.1 to 1.7; $p = 0.02$) and attenuated to marginal significance after BMI adjustment ($p = 0.13$). Improved CRF over 7 years was associated with a reduced risk of developing diabetes (HR 0.4; 95% CI 0.2 to 1.0; $p = 0.04$) and the metabolic syndrome (HR 0.5; 95% CI 0.3 to 0.7; $p<0.001$), but the strength and significance of these associations was reduced after accounting for changes in weight
Cardiorespiratory fitness	Boreham *et al*[29] The Northern Ireland Young Hearts Project Quality score 5	10 1989–90–1992–3–1997–9	Boys 229 Girls 230	12 and 15 to 22.5	20 mSRT (no of completed laps)	TC, HCLc, BP, sum of four skinfolds	Boys CRF changes were modestly and negatively associated with TC, HDLc and SBP ($p>0.5$) Girls CRF changes were modestly and negatively associated with TC, HDLc and skinfold thicknesses ($p>0.17$), and significantly (negatively) associated with DBP ($p = 0.03$)
Cardiorespiratory fitness	Byrd-Williams *et al*[34] Study of Latino Adolescents at Risk Quality score	4 2001–5	Boys 84 Girls 76	11 to 15	Maximal treadmill test (measured Vo_{2max} expressed as l/min)	BF, soft lean tissue mass, and %BF measured by DXA	Boys CRF was a significant predictor of change in BF after adjusting for changes in lean tissue mass, Tanner stage, and age ($\beta = -0.001$, $p = 0.03$). That is, higher initial CRF was associated with less subsequent gain in body fat Girls CRF was not a significant predictor of change in BF after controlling for changes in Tanner stage, lean tissue mass and age ($\beta = 0.0005$, $p = 0.37$)

Continued

Table 3 Continued

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Cardiorespiratory fitness	Ferreira *et al*[31]	24	Boys 75	13–16 to 36 and 21–26 to 36	Maximal treadmill test (measured Vo_{2max} expressed as ml/min, as ml/kg/min and as ml/min/kg$^{2/3}$)	Carotid IMT and stiffness of the carotid, femoral and brachial arteries	Boys and girls
Cardiorespiratory fitness and body composition	Ferreira *et al*[33] The Amsterdam Growth and Health Longitudinal Study Quality score 5	23 1977–91	Boys 175 Girls 189	13 to 36	Maximal treadmill test (measured Vo_{2max} expressed as ml/min/kg). BMI, WC, sum of four skinfolds. Subcutaneous trunk fat (subscapular plus the suprailiac to the sum of skinfolds)	Prevalence of the metabolic syndrome	Boys and girls Subjects with the metabolic syndrome at the age of 36 years, compared with those without the syndrome, had (from adolescence to the age of 36 years) a more marked increase in BF and in subcutaneous trunk fat, and a more marked decrease in CRF
Cardiorespiratory fitness	Koutedakis *et al*[32]	2 three time point	210 204 198	12.3 13.3 14.3	20 mSRT (estimated Vo_{2max} (expressed as ml/kg/min)	%BF estimated from skinfolds (triceps and medial calf)	Boys and girls Vo_{2max} was inversely associated with changes in BF ($\beta = -0.09$; $p \leqslant 0.05$)
Cardiorespiratory, motor and musculoskeletal fitness	Twisk *et al*[28]	20	Boys 132 Girls 145	13 to 32	Maximal treadmill test (measured Vo_{2max} expressed as l/min, ml/kg/min and the maximal slope), motor fitness (index of muscular strength, flexibility, speed of movement and coordination)	TC, HDLc, SBP, DBP, sum of four skinfolds and W/H	Boys and girls CRF (expressed as ml/kg/min) in 13–16-year-old group was negatively associated with sum of skinfolds, TC/HDLc and with SBP at 32 years of age in men and women CRF (expressed as ml/min) was negatively associated with BP in men, TC, sum of four skinfolds and W/H ($p<0.05$)
	The Amsterdam Growth and Health Longitudinal Study	1985	Boys 80	13–16 to 32			CRF (expressed as maximal slope) in 13-year-old group was negatively associated with sum of skinfolds and TC at 32 years of age in men and women
	Quality score 5	1996–7	Girls 96				Neuromotor fitness was positively related to SBP ($\beta = 0.11$; $p<0.01$) and inversely to the sum of four skinfolds ($\beta = 0.21$; $p<0.01$). Neuromotor fitness was not associated with TC, HDLc or TC/HDLc
Body composition	Baker *et al*[44] Quality score 5	5 1955–60	Boys 139 857 Girls 136 978	7–13 to ⩾23	BMI	CHD events	Boys and girls The risk of any CHD event, a non-fatal event and a fatal event among adults was positively associated with BMI at 7–13 years of age for boys and 10–13 years of age for girls. Adjustment for birth weight strengthened the results
Body composition	Bjorge *et al*[53] Quality score 5	34.9	226 682	14–19 to 58–63	BMI	Mortality	Adolescent obesity was related to increased mortality in middle age from several important causes. Higher BMI at adolescence was associated with an increased relative risk of death from endocrine, nutritional and metabolic diseases and from diseases of the circulatory system. The relative risks of death from diseases of the respiratory system and symptoms, signs, abnormal findings and ill-defined causes were increased in the group with higher BMI (>85th percentile)
Body composition	Engeland *et al*[54] Quality score 5	31.5	227 003	14–19 to 45–50	BMI	Mortality	An increasing risk of death by increasing BMI in adolescence was observed. Mortality among men whose baseline BMI was between the 85th and 95th percentiles and above the 95th percentile in the US reference population was 30% and 80% higher, respectively, than that among those whose baseline BMI was between the 25th and 75th percentiles. The corresponding rates among women were 30% and 100%

Continued

Table 3 Continued

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Body composition	Franks *et al*[48] Quality score 5	~9	1604	5–19 to 14–28	BMI and WC	Incidence of type 2 diabetes	Boys and girls In 5–9-year-old subjects, WC was the strongest and single significant modifiable predictor of diabetes. In 10–14-year-old subjects, the strongest independent modifiable predictors were 2-h glucose, BMI and A1C, whereas in the 15–19-year-old subjects, the strongest predictors were 2-h glucose, WC and A1C. When the age groups were combined (ie, 5–19 years) the independent modifiable predictors were BMI, fasting glucose, 2-h glucose and HDLc
Body composition	Gunnell *et al*[51] The Boyd Orr Cohort Quality score 5	57	Boys 1165 Girls 1234	2–14 to 59–71	BMI	Mortality	Boys and girls All-cause and cardiovascular mortality were associated with higher childhood BMI. Compared with those with BMI between the 25th and 49th centiles, the HR (95% CI) for all-cause mortality in those above the 75th BMI centile for their age and sex was 1.5 (1.1 to 2.2) and for ischaemic heart disease it was 2.0 (1.0 to 3.9). There was also a suggestion of a non-linear association with overall mortality; those in the 25–49th centile of the BMI distribution had the lowest mortality rates
Body composition	Juonala *et al*[41] The Cardiovascular Risk in Young Finns Study Quality score 5	21	1081	3–18 to 24–39	BMI	Carotid artery ITM and obesity	Boys and girls Being overweight or obese in adolescence carried about a 4-fold increased risk of being obese in adulthood. Subjects who had been overweight/obese in youth had significantly higher carotid IMT values in adulthood compared with subjects who had been lean in youth. Subjects who had been obese in youth but were non-obese as adults had comparable IMT values as subjects who had remained consistently non-obese. On the other hand, gaining weight and being consistently obese/overweight from youth to adulthood were both associated with increased IMT in adulthood
Body composition	Juonala *et al*[40] The Cardiovascular Risk in Young Finns Study Quality score 5	21	2255	10.7 to 37.1	Skinfold thickness	Carotid artery compliance, Young's elastic modulus and stiffness index	Boys and girls Childhood obesity (above age and sex-specific 80th percentile for skinfold thickness) predicted decreased carotid artery compliance, increased Young's elastic modulus and increased stiffness index in adulthood
Body composition	Lawlor and Leon[45] Aberdeen Children of the 1950s Prospective Cohort Study Quality score 5	23 1981–2004	11 106	4.9 to 28	BMI	Risk of CHD and stroke	Boys and girls There was no association between childhood BMI and CHD risk. There was no linear association between childhood BMI and stroke risk, but those who were obese in childhood (top 2.5% of the BMI distribution) compared with all others had an increased risk of stroke; the adjusted (for gender, father's occupational social class at birth, no of siblings and birth weight) HR was 2.41 (95% CI 1.00 to 5.86)
Body composition	Lawlor *et al*[46] Boyd Orr cohort Christ's Hospital Glasgow Alumni Quality score 5	~16 ~1988–2004	Boyd Orr Cohort Boys 1344 Girls 1242 Christ's Hospital Boys 1440 Glasgow Alumni Boys 2637 Girls 7918	2–15 9–18 16–22	BMI	Risk of adult ischaemic heart disease and stroke	Boys and girls BMI was not associated with future risk of ischaemic heart disease or stroke in any cohort. The pooled (all three cohorts) adjusted HR per SD of early life BMI was 1.09 (95% CI 1.01 to 1.19) for ischaemic heart disease and 0.94 (95% CI 0.82 to 1.08) for stroke. The pooled HR of ischaemic heart disease when participants who were overweight or obese for their age were compared with all other participants was 1.34 (95% CI 0.95 to 1.91), and no association was found between overweight or obesity and stroke risk. The effects of BMI did not vary by cohort or by age

Continued

Table 3 Continued

Fitness component	Author/study quality score	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
Body composition	Must *et al*[52] Quality score 5	~60 1922–35, 1988	508	13–18 to 73–78	BMI	Risk of mortality from all causes and disease-specific mortality	Boys and girls Overweight in adolescents was associated with an increased risk of mortality from all causes and disease-specific mortality among men, but not among women. The relative risks among men were 1.8 (95% CI 1.2 to 2.7; p = 0.004) for mortality from all causes and 2.3 (95% CI 1.4 to 4.1; p = 0.002) for mortality from CHD. The risk of morbidity from CHD and atherosclerosis was increased among men and women who had been overweight in adolescence
Body composition	Oren *et al*[47] The Atherosclerosis Risk in Young Adults Study Quality score 5	~15	750	12–16 to 27–30	BMI	Carotid IMT	Boys and girls One SD increase in adolescent BMI was associated with 2.3 mm (95% CI 1.3 to 3.3) increase in mean common carotid IMT in young adults after adjustment for gender, adolescent age, adolescent BP, puberty stage and lumen diameter. Further adjustment for adult CVD risk factors did not change the relationship, whereas adjustment for adult BMI attenuated the association. Subjects who remained in the upper BMI distribution from adolescence into young adulthood had a significantly higher common carotid IMT compared with those who showed relative weight loss over time
Body composition	Raitakari *et al*[4] Cardiovascular Risk in Young Finns Study Quality score 5	21 1980 2001–2	3596 2283	3–18 24–39	BMI	Carotid artery IMT	Boys and girls In multivariable models adjusted for age and sex, IMT in adulthood was significantly associated with childhood BMI (p = 0.007) and with adult BMI (p<0.001). High levels (ie, extreme age and sex-specific 80th percentile) of BMI in 12–18-year-old adolescents was directly related to carotid IMT measured in young adults at ages 33–39 years (p<0.001 for both men and women), and remained significant after adjustment for contemporaneous risk variables
Body composition	van Lenthe *et al*[42] The Amsterdam Growth and Health Longitudinal Study Quality score 5	23 1977–91	Boys 84 Girls 98	13–27 to 36–50	S/T and sum of four skinfolds	BP, TC, HDLc and TC/HDLc	Boys and girls Increase in the S/T ratio was significantly associated with increase in SBP. After adjustment for sum of skinfolds and the behavioural variables (physical activity, smoking and alcohol intake), the association remained statistically significant In men, the increase of the S/T was significantly associated with a decrease in TC level. However, after adjustment for sum of skinfolds, this association no longer remained statistically significant. The increase in the S/T ratio was statistically significantly associated with decrease in level of HDLc, also after adjustment for confounders
Body composition	Sivanandam *et al*[43] Quality score 5	14 1985–6 1999–2000	231 132	13 to 27	BMI, FFM and BF (measured with DXA)	Left ventricular mass	Boys and girls BMI at 13 years was highly correlated with LVMI at 13 and 27 years. The cross-sectional correlation of LVMI and BMI at 13 years (r = 0.38, p<0.001) had strengthened considerably by 27 years (r = 0.55, p<0.001) A BMI increase >5.5 kg/m^2 from 13 to 27 years was associated with a significantly greater increase in the LVMI (p<0.001) than a BMI change <5.5 kg/m^2, and this relation was similar in children who were thin and heavy at baseline. In young adulthood, the relation of LVMI to FFM was weaker than that of LVMI to BF

BF, body fat; %BF, percentage of body fat; BMI, body mass index; BP, blood pressure; CHD, coronary heart disease; CRF, cardiorespiratory fitness (also refers to maximum oxygen consumption ($V_{O_{2max}}$)); CVD, cardiovascular disease; DBP, diastolic blood pressure; DXA, dual energy *x* ray absorptiometry; FFM, fat-free mass; HDLc, high-density lipoprotein cholesterol; HR, hazard ratio; IMT, intima media thickness; LDLc, low-density lipoprotein cholesterol; LVMI, left ventricular mass index; OR, odds ratio; SS/SSF, subscapular plus supraespinale skinfold/subscapular plus supraespinale lus biceps plus triceps skinfolds; S/T, subscapular/triceps skinfolds ratio; TC, total cholesterol; TG, triglycerides; 20 mSRT; 20 m shuttle run test; WC, waist circumference; W/H, waist to hip ratio.

musculoskeletal fitness was assessed in eight (19%), motor fitness in three (7%) and body composition in 21 studies (50%). One study examined the association between perceived physical fitness and weight gain from adolescence to early adulthood.[17]

Quality assessment

Table 2 shows the list of included longitudinal studies with quality scores. The overall agreement between the two reviewers was 90% (κ = 0.809). Disagreement was solved in a consensus meeting. We defined 33 studies as high quality (score ⩾3) and four as low quality (score 2). There were no studies with a quality score below 2. A total of 21 studies had the highest score (score 5), from which seven dealt with cardiorespiratory fitness, one with motor and musculoskeletal fitness and 15 with body composition.

Levels of evidence

Table 3 shows the results of the data extraction of the studies reporting the predictive validity of health-related physical fitness for CVD risk factors and disease in children and adolescents.

Cardiorespiratory fitness

Seventeen high-quality studies[18–34] reported on the prospective relationship between cardiorespiratory fitness and CVD risk factors and disease in children and adolescents. Several studies reported that cardiorespiratory fitness in childhood and adolescence is a predictor of CVD risk factors, such as abnormal blood lipids,[18–20 24 25 28–31 33] high blood pressure,[18 20 30 35] and excess of overall and central adiposity[18–21 24 25 28 29 34 36] later in life. Two studies reported that cardiorespiratory fitness in childhood and adolescence is a predictor of the metabolic syndrome[30 33] and arterial stiffness[26 31] later in life. Two studies examined the association between changes in cardiorespiratory fitness and changes in CVD risk factors, such as total cholesterol, high-density lipoprotein (HDL) cholesterol, triglycerides and total and central adiposity.[18 25] One study examined the association between changes in cardiorespiratory fitness and changes in intima media thickness (IMT), carotid distension and compliance,[31] and Carnethon *et al*[30] studied the relationship between changes in cardiorespiratory fitness and diabetes, metabolic syndrome and weight gain over 7 and 15 years.

Carnethon *et al*[30] reported that adolescents with low cardiorespiratory fitness (<20th percentile) were three to sixfold more likely to develop the metabolic syndrome as well as to develop diabetes and hypertension than adolescents with high cardiorespiratory fitness (⩾60th percentile; all $p<0.001$). They also reported that improved cardiorespiratory fitness over 7 years was associated with a reduced risk of developing the metabolic syndrome (hazard ratio (HR) 0.5; 95% CI 0.3 to 0.7; $p<0.001$) and diabetes (HR 0.4; 95% CI 0.2 to 1.0; $p = 0.04$) but the strength and significance of these associations was reduced after accounting for changes in body weight. Furthermore, they reported that among those who became obese earlier in life (possibly during childhood or adolescence), cardiorespiratory fitness did not protect against developing diabetes or the metabolic syndrome. Increasing cardiorespiratory fitness between visits was associated with a lower risk of developing both diabetes and the metabolic syndrome, suggesting that two very important risk factors for coronary heart disease and mortality may be modified by improving fitness over time.[30]

Overall, these findings are consistent for both boys and girls, although there is one high-quality study showing that cardiorespiratory fitness was not a significant predictor of change in body fat after controlling for changes in pubertal status, lean tissue mass and age in girls ($\beta = 0.0005$, $p = 0.37$).[34] There is also one high-quality study showing that cardiorespiratory fitness at the age of 16 years is not associated with markers of overall and central adiposity, HDL cholesterol, or systolic blood pressure at the age of 34 years.[23]

Results from low-quality studies are consistent with those observed in high-quality studies, except the study by McGavock *et al*[37] (low-quality study), which reported that cardiorespiratory fitness is not associated with changes in systolic blood pressure.

In summary, there is strong evidence indicating that cardiorespiratory fitness in childhood and adolescence is a predictor of CVD risk factors such as abnormal blood lipids, high blood pressure and overall and central adiposity later in life. There is moderate evidence indicating that cardiorespiratory fitness in childhood and adolescence is a predictor of the metabolic syndrome and arterial stiffness later in life. Finally, there is moderate evidence indicating that changes in cardiorespiratory fitness are associated with CVD risk factors. Due to a limited number of studies (one for each outcome), there is inconclusive evidence indicating that changes in cardiorespiratory fitness are associated with changes in IMT, carotid distension and compliance, weight gain, diabetes and the metabolic syndrome.

Musculoskeletal fitness

Four high-quality studies,[18 23 25 28] and one low-quality study[38] reported on the prospective relationship between musculoskeletal fitness and CVD risk factors and disease in children and adolescents. Changes in muscular strength from childhood to adolescence seem to be negatively associated with changes in overall adiposity,[18 23 25 28] whereas the association between changes in muscular strength and changes in central adiposity are less evident.[18 25] Janz *et al*[25] reported that changes in muscular strength were negatively associated with changes in systolic blood pressure ($p<0.05$) after controlling for age, gender, fat-free mass and pubertal status in both boys and girls, whereas no associations between changes in muscular strength and changes in blood pressure, total cholesterol, HDL or triglycerides were observed in Danish youth.[18]

In summary, there is strong evidence indicating that muscular strength changes from childhood to adolescence are negatively associated with changes in overall adiposity, whereas there is moderate evidence indicating such an association for central adiposity. There is inconclusive evidence that muscular strength changes are associated with changes in other CVD risk factor such as systolic blood pressure or blood lipids and lipoproteins.

Motor fitness

There is one high-quality study[28] and one low-quality study[38] reporting the prospective relationship between motor fitness and CVD risk factors in children and adolescents. Twisk *et al*[28] computed an index of neuromotor fitness with measures of muscular strength, flexibility, speed of movement and coordination, and they reported that neuromotor fitness was positively related to systolic blood pressure ($\beta = 0.11$; $p<0.01$) and inversely to the sum of four skinfolds ($\beta = 0.21$; $p<0.01$). They also reported that neuromotor fitness was not associated with total cholesterol, HDL cholesterol, or the ratio of both.

In summary, there is inconclusive evidence indicating that motor fitness in childhood and adolescence is a predictor of CVD risk factors later in life.

Body composition

There are 14 high-quality studies,[4 21 22 33 39–48] and three low-quality studies[37 49 50] reporting the prospective relationship between body composition and CVD risk factors and disease in children and adolescents. Several studies reported that body composition in childhood and adolescence is a predictor of CVD risk factors, such as blood lipids[22 39 42] and carotid artery

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IMT.[4 40 41 47] Garnett *et al*[39] reported that children who were overweight or obese at 8 years of age were seven times (odds ratio (OR) 6.9; 95% CI 2.5 to 19.0; p<0.001) as likely to have CVD risk clustering in adolescence as were their peers who were not overweight or obese. They also reported that those with an increased central adiposity (measured with waist circumference) at the age of 8 years were four times (95% CI 3.6; 1.0 to 12.9; p = 0.061) as likely to have CVD risk clustering in adolescence as were children with a smaller waist circumference.

Several high-quality studies[51–54] reported an increased risk of death in those individuals with higher BMI in adolescence. Mortality among men whose baseline BMI was between the 85th and 95th percentiles and above the 95th percentile in the US reference population was 30% and 80% higher, respectively, than that among those whose baseline BMI was between the 25th and 75th percentiles. The corresponding rates among women were 30% and 100%.[54] Findings from the same cohort revealed that higher BMI at adolescence was associated with an increased relative risk of death from endocrine, nutritional and metabolic diseases, and from diseases of the circulatory system.[53] These findings apply to both boys and girls. Must *et al*[52] reported that overweight in adolescents was associated with an increased risk of mortality from all causes and disease-specific mortality among men. The relative risks among men were 1.8 (95% CI 1.2 to 2.7; p = 0.004) for mortality from all causes and 2.3 (95% CI 1.4 to 4.1; p = 0.002) for mortality from coronary heart disease. They also reported that the risk of morbidity from coronary heart disease and atherosclerosis was increased among men and women who had been overweight in adolescence.

In summary, there is strong evidence indicating that body composition in childhood and adolescence is a predictor of CVD risk factors such as blood lipids and carotid artery IMT. There is also strong evidence indicating that high BMI in childhood and adolescence increases the risk of death later in life.

Health-related physical fitness predictive validity for low back pain

A total of five longitudinal studies were included (table 4). Musculoskeletal fitness was assessed in four studies and body composition in two studies. There were no studies examining the prospective association between cardiorespiratory or motor fitness and low back pain.

Quality assessment

Table 4 shows the list of included longitudinal cohort studies with quality scores. The overall agreement between the two reviewers was 100% ($\kappa = 1$). We defined five studies as high quality (score $\geqslant$3). One study had a score of 3,[55] two studies had a score of 4,[56 57] and two studies had the maximum score, that is 5.[58 59] There were no studies with a score below 3.

Levels of evidence

Table 5 shows the results of the data extraction of the studies reporting the predictive validity of physical fitness for low back pain in children and adolescents.

Musculoskeletal fitness

Four high-quality studies reported on the prospective relationship between musculoskeletal fitness and low back pain in children and adolescents, with inconsistent results.[55–57 60]

Kujala *et al*[55] reported that tightness of the hip flexor muscles was associated with lifetime cumulative incidence of low back pain, whereas Burton *et al*[57] reported that lumbar sagittal flexibility was not associated with self-reported low back pain. Likewise, Barnekow-Bergkvist *et al*[56] did not observe an association between flexibility and low back pain except for the back extension test, which was negatively associated with low back symptoms in women. Only one study reported that muscular strength, measured by the two-hand lift test at the age of 16 years, was associated with a significantly decreased risk of low back problems in adulthood in women.[56]

In summary, there is inconclusive evidence indicating that flexibility or muscular strength in childhood and adolescence is a predictor of low back pain later in life.

Body composition

Two high-quality[59 60] studies reported on the prospective relationship between body composition and low back pain in children and adolescents. BMI was the only component available in these studies. Mikkelsson *et al*[60] did not observe an association between BMI and low back pain in either boys or girls. Likewise, Hestbaek *et al*[59] reported that adolescent overweight was not associated with adult low back pain.

In summary, the findings indicate that there is no association between BMI and low back pain, and the evidence is moderate.

Health-related physical fitness predictive validity for quality of life and wellbeing

We were not able to find any longitudinal study reporting on the associations between physical fitness and quality of life in children and adolescents. One longitudinal study explored the links between participation in physical activity and global self-esteem among girls from childhood into early adolescence.[61] They reported that participating in physical activity can lead to positive self-esteem among adolescent girls, particularly for younger girls and those at greatest risk of overweight. Knowing the association between physical activity and cardiorespiratory fitness in children and adolescents,[62–64] we could presume that high levels cardiorespiratory fitness during childhood might be a predictor of positive self-esteem later in life. This issue warrants further investigation.

Table 4 List of included prospective cohort studies with quality scores with reference to predictive value of physical fitness for low back pain in children and adolescents

Study	Fitness dimension	Selection of population	Description of outcome	Follow-up time	Confounder adjustment	Risk estimates	Total score
High-quality studies							
Kujala *et al*[55]	Musculoskeletal fitness	1	1	1	0	0	3
Barnekow-Bergkvist *et al*[56]	Musculoskeletal and motor fitness	1	1	1	0	1	4
Burton *et al*[57]	Musculoskeletal fitness	1	1	1	0	1	4
Mikkelsson *et al*[60]	Musculoskeletal fitness and body composition	1	1	1	1	1	5
Hestbaek *et al*[59]	Body composition	1	1	1	1	1	5

Table 5 Prospective studies on predictive validity of physical fitness for low back pain in children and adolescents

Fitness component	Author/study	Years of follow-up	Subjects	Age (years)	Fitness test	Outcome variables	Results
High-quality studies							
Musculoskeletal and body composition	Kujala *et al*[55]	1	Boys 58	10.3–13.3	Height, BF (skinfolds thickness), endurance strength of the trunk (curl-ups and back test), maximal isometric strength (trunk extension), tightness of the hip flexor muscles, and the hamstrings muscles, systemic hypermobility and lumbar sagital mobility	Incidence of low back pain during the past 12 months (self-reported)	Boys and girls
	Quality score 3		Girls 80	11–14			Only tightness of the hip flexor muscles was associated with lifetime cumulative incidence of low back pain
Musculoskeletal and motor fitness	Barnekow-Bergkvist *et al*[56]	18	Boys 220	16	Muscular endurance (static, back extension; dynamic, curl-up and bench press), strength (static, two-hand lift and hand grip), flexibility (neck lateral flexion and rotation, hip flexion/hamstring flexibility, hip extension/iliopsoas flexibility) and standing balance	Prevalence of symptoms in the neck, shoulders, and low back (self-reported)	Boys and girls
	Quality score 4	1974	Girls 205				
		1992	Boys 157	34			Neck-shoulder symptoms: after adjusting for covariation with sociodemographic and individual factors, lifting was negatively related to symptoms. In addition, high performance in the bench press test at the age of 16 years was associated with a decreased risk of neck–shoulder problems in adulthood for the men. A strong handgrip and good neck flexibility in adulthood were negatively related to symptoms
			Girls 121				Low back symptoms: after adjusting for covariates with sociodemographic and individual factors, high performance in the two-hand lift test in the men and high performance in the back extension test in the women were negatively related to symptoms. In addition, high performance in the two-hand lift test at the age of 16 years was associated with a significantly decreased risk of low back problems in adulthood in women
Musculoskeletal fitness	Burton *et al*[57]	5	216	11	Lumbar sagittal flexibility, measured using the flexicurve technique	Incidence and lifetime prevalence of low back pain (self-reported)	Boys and girls
	Quality score 4	1985–90		to 16			There were no statistically significant relationships between flexibility and any of the low back pain variables measured
Musculoskeletal fitness and body composition	Mikkelsson *et al*[60]	25	Boys 801	12–17 to 37–42	BMI, sit and reach and 30-s sit-up test	Self-reported low back pain and physician diagnosed tension neck and knee injury	Boys
							No association between BMI and low back pain was observed in either boys or girls
							Men in the highest baseline flexibility third were at lower risk of tension neck than those from the lowest third (OR 0.51; 95% CI 0.28 to 0.93)
							Men from the highest baseline endurance strength third were at higher risk of knee injury than those from the lowest third (OR 1.96; 95% CI 1.05 to 3.64)
	Quality score 5	1976–2001	Girls 886				The risk of tension neck increased with each unit increase in BMI by 9% in men
							Girls
							Women from the highest baseline endurance strength third were at lower risk of tension neck than those from the lowest third (OR 0.60; 95% CI 0.40 to 0.91)
							An increase of one unit of BMI increased the risk of knee injury by 16%. The risk of tension neck increased with each unit increase in BMI by 5% in women
Body composition	Hestbaek *et al*[59]	8	9600 twins	12–22	BMI	No of days with low back pain during the past year at baseline in 1994 and at follow-up in 2002	Boys and girls
				to			No associations were observed between adolescent overweight and adult low back pain
	Quality score 5	1994–2002		20–26			

BMI, body mass index; BF, body fat; OR, odds ratio.

DISCUSSION

The present systematic review shows that there is strong evidence indicating that: (1) higher levels of cardiorespiratory fitness in childhood and adolescence are associated with a healthier cardiovascular profile later in life; (2) muscular strength improvements from childhood to adolescence are inversely associated with changes in overall adiposity; and (3) a healthier body composition in childhood and adolescence is associated with a healthier cardiovascular profile and a lower risk of death later in life.

We have also shown that there is moderate evidence indicating that: (1) higher levels of cardiorespiratory fitness in childhood and adolescence reduce the risk of developing the metabolic syndrome and arterial stiffness later in life; (2) increasing cardiorespiratory fitness is inversely associated with changes in blood lipids and lipoproteins; (3) muscular strength improvements from childhood to adolescence are inversely associated with changes in central adiposity; and (4) there is no association between body composition (ie, BMI) and low back pain.

Finally, due to a limited number of studies, the results also suggest that there is inconclusive evidence showing that: (1) changes in cardiorespiratory fitness are associated with changes in IMT, carotid distension and compliance, weight gain, diabetes and the metabolic syndrome; (2) changes in muscular strength are associated with changes in systolic blood pressure or blood lipids and lipoproteins; (3) motor fitness in childhood and adolescence is a predictor of CVD risk factors later in life; and (4) motor fitness in childhood and adolescence is a predictor of low back pain later in life.

Heterogeneity

The results of the present systematic review should be interpreted with caution due to the variety of tests used to assess physical fitness, the outcomes measures, follow-up time (from one year to 57 years), age of the participants and adjustment for confounders.

Physical fitness tests

Cardiorespiratory fitness was assessed by means of six different tests: 20 m shuttle run test,[21 29 32 37] 1.5 mile run/walk test,[23] maximal treadmill test,[19 24 28 30 31 33 34 49] maximal[25] and submaximal[18 20 26 27] cycle ergometer test and the 1600 m run test.[38] The outcome of the tests was also expressed in different ways: measured maximum oxygen consumption ($V_{O_{2max}}$),[18–20 24 25 28 31 33 34] estimated $V_{O_{2max}}$,[23 26 27 32] duration of the test[30 38 49] and number of completed laps in the 20 m shuttle run test.[21 29] Finally, $V_{O_{2max}}$ was expressed in absolute terms (l/minute),[20 24 28 31 34] or in relative terms as ml/kg per minute,[18 20 23 26 28 31–33 37] as ml/minute per kg of fat-free mass[27] or as ml/minute per $kg^{2/3}$.[19 25 31]

Musculoskeletal fitness was assessed by the handgrip strength test,[19 28 38 55] bent arm hang,[38] bench press,[19 56] standing broad jump,[38] sit-ups,[19 38] curl-ups,[55] sit and reach[28 38 55 56] and the shoulder stretch test.[38]

Motor fitness was assessed by the 4 × 10 m shuttle run test,[19 28 38] the 50 m run test[19 28 38] and the standing balance test.[56]

Body composition was mainly assessed by BMI,[4 22 33 39 41 43–54 60] yet several studies also included measures on skinfold thickness,[22 33 40 42 50 55] and waist circumference.[33 39 48 49]

Outcome measures

Most of the studies used single and continuous CVD risk factors, such as blood lipids, blood pressure, insulin sensitivity, inflammatory markers, or overall and central adiposity, whereas others gave clear details of the presence of the disease/syndrome (eg, obesity, hypertension, dyslipidaemia, diabetes, or the metabolic syndrome). In the studies related to low back pain, the outcome was dichotomous, as the presence or absence of low back pain, which was self-reported.

Follow-up

The follow-up time of the selected studies ranged from one to 5 years,[17 21 24 25 32 34 37 38 44 55 57] to more than 5 years,[18 20 27 39 48] more than 10 years,[22 23 29 30 43 46 47 49 56] more than 20 years,[4 28 31 33 40–42 45 50 60] more than 30 years[53 54] and more than 50 years.[51] One study followed the participants for 60 years.[52] The longest studies are those investigating the prospective association between BMI and the risk of death.[51–54]

Adjustment for confounders

Most of the studies adjusted for confounders, whereas several studies did not adjust for any confounder.[17–22 27 37–39 49 50] Not adjusting for potential confounders such as sex (if applicable), age, pubertal status, baseline health status or socioeconomic status, could lead to a different results, that is, to an under or an overestimation of the findings. The overall findings of the present systematic review would not have materially changed if we had restricted the analyses to those studies with satisfactory adjustment for potential confounders.

Quality assessment

The cut-off points and assumptions established to define the levels of evidence might have influenced the results. To investigate the influence of these cut-offs on the findings, we performed sensitivity analyses after varying those assumptions. Due to the limited number of studies, this was not performed on the low back pain studies.

We calculated total quality score by counting up the number of positive items. All the items had the same weight, despite the fact that some items might be more relevant for the quality assessment than others. The quality items on the time between the measurement of physical fitness test and the health outcome, adjustment for confounders and standard errors and/or confidence intervals might be more important for the level of evidence than the items on the selection of the population or the description of the health outcomes.

We gave to those more relevant items a double weight, that is, we multiplied them by 2, which led to a maximum total score of 8. We defined studies as high quality if they had a total score of 6 or higher, and we defined studies as low quality if the total score was between 4 and 5. This would have excluded from the high-quality list the studies by Andersen *et al*,[20] Hasselstrom *et al*,[18] Psarra *et al*,[21] Twisk *et al*[19] and Srinivasan *et al*.[22] However, this would not have affected the overall conclusions.

Changing the cut-off points regarding the qualification of studies as high or low quality would have also affected the number of high-quality studies. We changed the cut-off points needed to score a study as high quality from a total score of 3 to a score of 4. Five studies[18–22] would have been excluded, yet this would not have changed the overall conclusions.

Overall, the conclusions do not materially change after modifying the cut-off points and assumptions used to rank the longitudinal studies. Therefore, the findings of this systematic review can be considered stable and robust.

What is already known on this topic

Physical fitness is emerging as an important marker of health already in childhood and adolescence, yet most of the evidence comes from cross-sectional studies.

What this study adds

- There is evidence coming from longitudinal studies that a higher level of physical fitness (ie, cardiorespiratory fitness, muscular strength and body composition) in childhood and adolescence is associated with a healthier cardiovascular profile and with a lower risk of developing CVD later in life.
- A healthier body composition in childhood and adolescence is also associated with a lower risk of death in adulthood.
- Improvements in physical fitness from childhood to adulthood are associated with positive changes in CVD risk factors.

Implications

These epidemiological observations should inform experimental/mechanistic studies the exploration of biological mechanisms that link physical fitness in children and adolescents with health/disease/death later in life. We still need further studies to know whether effective interventions to improve physical fitness in the first decades of life will reduce the burden of CVD-related morbidities and mortality later in life. This knowledge will also allow the formulation of public health strategies to prevent obesity-related morbidities worldwide.

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