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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 for cardiovascular disease 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 cardiovascular disease risk factors, events and syndromes as well as the results of 5 studies reporting the predictive validity of physical fitness for low back pain in children and adolescents were summarised.

We found strong evidence indicating that: higher levels of cardiorespiratory fitness at childhood and adolescence are associated with 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 at 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 cardiovascular disease risk factors, and between cardiorespiratory fitness and the risk of developing metabolic syndrome and arterial stiffness. We also found moderate evidence on the lack of relationship between body composition and low back pain.

Due to a limited number of studies, we found inconclusive evidence for a relationship between muscular strength or motor fitness and cardiovascular disease risk factors, and between flexibility and low back pain.

Key words: Predictive validity, cardiorespiratory fitness, musculoskeletal fitness, cardiovascular disease risk factors, children.

INTRODUCTION

Cardiovascular diseases (CVD) are 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 recognized 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 the society. Around 50% of the population report musculoskeletal pain at one or more sites in the last 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 life time prevalence of low back pain ranges from 7 to 72%.[6]

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

Whether physical fitness is an important marker of health already in childhood and adolescence is still under debate[11-13] since most of the evidence comes from cross-sectional studies. In the last 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 if physical fitness should or 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 for CVD risk factors, type 2 diabetes, metabolic syndrome, and cardiovascular events later in life. We also examined if there is evidence that physical fitness in childhood and adolescence is a predictor for 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 **A**ssessing **L**evels of **PH**ysical **A**ctivity 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 the recent knowledge on the 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 predicts future disease/better health status? We selected longitudinal cohort studies examining the association between physical fitness in children and adolescents and future:

1) Cardiovascular disease risk factors: blood lipids, blood pressure, insulin sensitivity, inflammatory markers, and overall and central adiposity.

2) Cardiovascular disease/syndromes: obesity, hypertension, dyslipidemia, diabetes, and metabolic syndrome.

3) Low back pain.

4) Quality of life and well-being, also called positive health outcomes: school performance, self-esteem, mood-status, socialization, resilience (i.e., the positive capacity of people to cope with stress), and risk avoidance behaviour.

The health-related fitness components and factors/traits are depicted in Figure 1.[14] Definitions of the concepts used in the manuscript can be seen in the Supplemental Material.

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 where 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, waist circumference, overall adiposity, central adiposity, overweight, obesity, risk factors, risk score cardiovascular disease, metabolic syndrome, blood glucose, glucose tolerance, insulin resistance, insulin sensitivity, blood lipids, dyslipidemia, diabetes, blood pressure, hypertension, inflammatory markers, bone mineral density, bone mineral content, school performance, self-esteem, mood-status, socialization, 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 not any exclusion criteria in regards 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 summarized 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 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 $P \leq 0.05$ as statistically significant.

RESULTS

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

A total of forty two longitudinal studies were included (Table 2). Cardiorespiratory fitness was assessed in 20 (48%) studies, musculoskeletal fitness was assessed in 8 (19%), motor fitness in 3 (7%), and body composition in twenty one 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% (Kappa = 0.809). Disagreement was solved in a consensus meeting. We defined thirsty three 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 twenty one studies had the highest score (score=5), from which seven dealt with cardiorespiratory fitness, one with motor and musculoskeletal fitness and fifteen 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.

a) 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 at 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 at childhood and adolescence is a predictor of 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 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, 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 3- to 6-fold more likely to develop 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 metabolic syndrome [hazard ratio, 0.5; 95% confidence interval (CI), 0.3-0.7; P<0.001], and diabetes (hazard ratio, 0.4; 95% CI, 0.2-1.0; 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 metabolic syndrome. Increasing cardiorespiratory fitness between visits was associated with a lower risk for developing both diabetes and 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, though 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 (β=0.0005, P=0.37).[34] There is also one high-quality study showing that cardiorespiratory fitness at the age of 16 is not associated with markers of overall and central adiposity, high density lipoprotein cholesterol, or systolic blood pressure at the age of 34.[23]

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

In summary, there is strong evidence indicating that cardiorespiratory fitness at 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 at childhood and adolescence is a predictor of metabolic syndrome and arterial stiffness later in life. Finally, there is moderate evidence indicating that changes in cardiorespiratory fitness are associated with cardiovascular disease 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 intima media thickness, carotid distension and compliance, weight gain, diabetes and metabolic syndrome.

b) 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 seems 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, high density lipoprotein 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 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.

c) 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 (β=0.11; P<0.01) and inversely to the sum of four skinfolds (β=0.21; P<0.01). They also reported that neuromotor fitness was not associated with total cholesterol, high density lipoprotein cholesterol, or the ratio of both.

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

d) Body composition: there are fourteen 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 at childhood and adolescence is a predictor of CVD risk factors, such as blood lipids[22 39 42] and carotid artery intima media thickness.[4 40 41 47] Garnett et al.[39] reported that children who were overweight or obese at 8 years of age were 7 times (odds ratio: 6.9; 95% CI: 2.5, 19.0; P<0.001) as likely to have CVD risk clustering in adolescence than 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 were 4 times (95% CI: 3.6; 1.0, 12.9; P=0.061) as likely to have CVD risk clustering in adolescence than were children with a smaller waist circumference.

Several high-quality studies[51-54] reported an increased risk of death in those persons with higher BMIs in adolescence. Mortality among males whose baseline BMI was between the 85th and 95th percentiles and above the 95th percentile in the U.S. 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 females 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 at childhood and adolescence is a predictor of CVD risk factors such as blood lipids and carotid artery intima media thickness. There is also strong evidence indicating that high BMI at 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 5 studies as high quality (score ≥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.

a) 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 sagital 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, 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 at childhood and adolescence is a predictor of low back pain later in life.

b) Body composition: two high-quality[59 60] studies reported on the prospective relationship between body composition and low back pain in children and adolescents. Body mass index was the only component available is these studies. Mikkelsson et al.[60] did not observe an association between BMI and low back pain in both boys and 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 well-being

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.

DISCUSSION

The present systematic review shows that there is strong evidence indicating that: 1) higher levels of cardiorespiratory fitness at 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 at 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 at childhood and adolescence reduce the risk of developing 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 (i.e., 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 intima media thickness, carotid distension and compliance, weight gain, diabetes and metabolic syndrome; 2) changes in muscular strength are associated with changes in systolic blood pressure or blood lipids and lipoproteins; 3) motor fitness at childhood and adolescence is a predictor of CVD risk factors later in life; and 4) motor fitness at 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 1 year to 57 years), age of the participants, and adjustment for confounders.

Physical fitness tests

Cardiorespiratory fitness was assessed by means of 6 different tests: 20m 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 1600m run test.[38] The outcome of the tests was also expressed in different ways: measured VO_{2max},[18-20 24 25 28 31 33 34] estimated VO_{2max},[23 26 27 32] duration of the test,[30 38 49] and number of completed laps in the 20m shuttle run test.[21 29] Finally, VO_{2max} was expressed in absolute terms (L/min),[20 24 28 31 34] or in relative terms as mL/kg/min,[18 20 23 26 28 31-33 37] as mL/min per kg of fat free mass[27] or as mL/min/kg$^{2/3}$.[19 25 31]

Musculoskeletal fitness was assessed by the handgrip strength test,[19 28 38 55] bent harm 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 4x10m shuttle run test,[19 28 38] the 50m 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 presence of the disease/syndrome (e.g., obesity, hypertension, dyslipidemia, diabetes, or metabolic syndrome). In the studies related to low back pain, the outcome was dichotomous, as presence or absence of low back pain, which was self-reported.

Follow up

The follow up time of the selected studies ranged from 1 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 during 60 years.[52] The longest studies are those investigating the prospective association between BMI and 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 would have 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 te 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 lead 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] Hasselstrøm et al.,[18] Psarra et al.,[21] Twisk et al.,[19] and Srinivasan et al.[22] Yet, 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 three to a score of four. Five studies [18-22] would have been excluded, yet this would not change 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.

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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Author Contributions

JRR drafted the manuscript. JRR and JCP read all the manuscripts and scored each of them. JRR and JS contributed to the concept and design of the systematic review. All the authors contributed to the interpretation and discussion of the results. JRR, JS, MS and MJC contributed to the concept and design of the ALPHA study. All the authors critically revised the manuscript.

Competing interests: None

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 (i.e., cardiorespiratory fitness, muscular strength and body composition) at childhood and adolescence is associated with a healthier cardiovascular profile and with a lower risk of developing cardiovascular diseases later in life.

A healthier body composition at childhood and adolescence is also associated with a lower risk of death at adulthood.

Improvements of physical fitness from childhood to adulthood are associated with positive changes in cardiovascular disease risk factors.

Figure legend

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

REFERENCES

1. **Smith SC,** Jr., Jackson R, Pearson TA, Fuster V, Yusuf S, Faergeman O, et al. Principles for national and regional guidelines on cardiovascular disease prevention: a scientific statement from the World Heart and Stroke Forum. *Circulation* 2004;**109**(25):3112-21.
2. **McGill HC,** Jr., McMahan CA, Herderick EE, Malcom GT, Tracy RE, Strong JP. Origin of atherosclerosis in childhood and adolescence. *Am J Clin Nutr* 2000;**72**(5 Suppl):1307S-1315S.
3. **Strong JP,** Malcom GT, Newman WP, 3rd, Oalmann MC. Early lesions of atherosclerosis in childhood and youth: natural history and risk factors. *J Am Coll Nutr* 1992;**11 Suppl**:51S-54S.
4. **Raitakari OT,** Juonala M, Kahonen M, Taittonen L, Laitinen T, Maki-Torkko N, 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**(17):2277-83.
5. **Andersen L,** Hasselstrøm H, Gronfeldt V, Hansen S, Froberg K. The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act* 2004;**1:6**.
6. **Jeffries LJ,** Milanese SF, Grimmer-Somers KA. Epidemiology of adolescent spinal pain: a systematic overview of the research literature. *Spine* 2007;**32**(23):2630-7.
7. **Dwyer T,** Sallis JF, Blizzard L, Lazarus R, Dean K. Relation of Academic Performance to Physical Activity and Fitness in Children. *Pediatr Exerc Sci* 2001;**13**:225-138.
8. **Sung RY,** Yu CW, So RC, Lam PK, Hau KT. Self-perception of physical competences in preadolescent overweight Chinese children. *Eur J Clin Nutr* 2005;**59**(1):101-6.
9. **Swallen KC,** Reither EN, Haas SA, Meier AM. Overweight, obesity, and health-related quality of life among adolescents: the National Longitudinal Study of Adolescent Health. *Pediatrics* 2005;**115**(2):340-7.
10. **Crews DJ,** Lochbaum MR, Landers DM. Aerobic physical activity effects on psychological well-being in low-income Hispanic children. *Percept Mot Skills* 2004;**98**(1):319-24.

11. **Ortega FB,** Ruiz JR, Castillo MJ, Sjostrom M. Physical fitness in childhood and adolescence: a powerful marker of health. *Int J Obes (Lond)* 2008;**32**(1):1-11.
12. **Castillo-Garzon M,** Ruiz JR, Ortega FB, Gutierrez-Sainz A. A mediterranean diet is not enough for health: physical fitness is an important additional contributor to health for the adults of tomorrow. *World Rev Nutr Diet* 2007;**97**:114-38.
13. **Ruiz JR,** Ortega FB, Meusel D, Harro M, Oja P, Sjöström M. Cardiorespiratory fitness is associated with features of metabolic risk factors in children. Should cardiorespiratory fitness be assessed in a European health monitoring system? The European Youth Heart Study. *J Public Health* 2006;**14**(2):94-102.
14. **Bouchard C**, Blair SN, Haskell WL. *Why study physical activity and health?*: In: Bouchard C, Blair SN, Haskell WL (eds.) Physical activity and health. Champaign, IL: Human Kinetics Books, 2007:3-22.
15. **Hamberg-van Reenen HH,** Ariens GA, Blatter BM, van Mechelen W, Bongers PM. A systematic review of the relation between physical capacity and future low back and neck/shoulder pain. *Pain* 2007;**130**(1-2):93-107.
16. **van Tulder MW,** Ostelo R, Vlaeyen JW, Linton SJ, Morley SJ, Assendelft WJ. Behavioral treatment for chronic low back pain: a systematic review within the framework of the Cochrane Back Review Group. *Spine* 2000;**25**(20):2688-99.
17. **Pietilainen KH,** Kaprio J, Borg P, Plasqui G, Yki-Jarvinen H, Kujala UM, et al. Physical inactivity and obesity: a vicious circle. *Obesity (Silver Spring)* 2008;**16**(2):409-14.
18. **Hasselstrom H,** Hansen SE, Froberg K, Andersen LB. Physical fitness and physical activity during adolescence as predictors of cardiovascular disease risk in young adulthood. Danish Youth and Sports Study. An eight-year follow-up study. *Int J Sports Med* 2002;**23 Suppl 1**:S27-31.
19. **Twisk JW,** Kemper HC, van Mechelen W. The relationship between physical fitness and physical activity during adolescence and cardiovascular disease risk factors at adult age. The Amsterdam Growth and Health Longitudinal Study. *Int J Sports Med* 2002;**23 Suppl 1**:S8-14.
20. **Andersen LB,** Hasselstrom H, Gronfeldt V, Hansen SE, Karsten F. The relationship between physical fitness and clustered risk, and tracking of clustered risk from

adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act* 2004;**1**(1):6.

21. **Psarra G,** Nassis GP, Sidossis LS. Short-term predictors of abdominal obesity in children. *Eur J Public Health* 2005.
22. **Srinivasan SR,** Bao W, Wattigney WA, Berenson GS. Adolescent overweight is associated with adult overweight and related multiple cardiovascular risk factors: the Bogalusa Heart Study. *Metabolism* 1996;**45**(2):235-40.
23. **Barnekow-Bergkvist M,** Hedberg G, Janlert U, Jansson E. Adolescent determinants of cardiovascular risk factors in adult men and women. *Scand J Public Health* 2001;**29**(3):208-17.
24. **Johnson MS,** Figueroa-Colon R, Herd SL, Fields DA, Sun M, Hunter GR, et al. Aerobic fitness, not energy expenditure, influences subsequent increase in adiposity in black and white children. *Pediatrics* 2000;**106**(4):E50.
25. **Janz KF,** Dawson JD, Mahoney LT. Increases in physical fitness during childhood improve cardiovascular health during adolescence: the Muscatine Study. *Int J Sports Med* 2002;**23 Suppl 1**:S15-21.
26. **Boreham CA,** Ferreira I, Twisk JW, Gallagher AM, Savage MJ, Murray LJ. Cardiorespiratory fitness, physical activity, and arterial stiffness: the Northern Ireland Young Hearts Project. *Hypertension* 2004;**44**(5):721-6.
27. **McMurray RG,** Bangdiwala SI, Harrell JS, Amorim LD. Adolescents with metabolic syndrome have a history of low aerobic fitness and physical activity levels. *Dyn Med* 2008;**7**:5.
28. **Twisk JW,** Kemper HC, van Mechelen W. Tracking of activity and fitness and the relationship with cardiovascular disease risk factors. *Med Sci Sports Exerc* 2000;**32**(8):1455-61.
29. **Boreham C,** Twisk J, Neville C, Savage M, Murray L, Gallagher A. Associations between physical fitness and activity patterns during adolescence and cardiovascular risk factors in young adulthood: the Northern Ireland Young Hearts Project. *Int J Sports Med* 2002;**23 Suppl 1**:S22-6.

30. **Carnethon MR,** Gidding SS, Nehgme R, Sidney S, Jacobs DR, Jr., Liu K. Cardiorespiratory fitness in young adulthood and the development of cardiovascular disease risk factors. *JAMA* 2003;**290**(23):3092-100.
31. **Ferreira I,** Twisk JW, Stehouwer CD, van Mechelen W, Kemper HC. Longitudinal changes in VO2max: associations with carotid IMT and arterial stiffness. *Med Sci Sports Exerc* 2003;**35**(10):1670-8.
32. **Koutedakis Y,** Bouziotas C, Flouris AD, Nelson PN. Longitudinal modeling of adiposity in periadolescent Greek schoolchildren. *Med Sci Sports Exerc* 2005;**37**(12):2070-4.
33. **Ferreira I,** Henry RM, Twisk JW, van Mechelen W, Kemper HC, Stehouwer CD. The metabolic syndrome, cardiopulmonary fitness, and subcutaneous trunk fat as independent determinants of arterial stiffness: the Amsterdam Growth and Health Longitudinal Study. *Arch Intern Med* 2005;**165**(8):875-82.
34. **Byrd-Williams CE,** Shaibi GQ, Sun P, Lane CJ, Ventura EE, Davis JN, et al. Cardiorespiratory Fitness Predicts Changes in Adiposity in Overweight Hispanic Boys. *Obesity (Silver Spring)* 2008.
35. **Twisk JW,** Kemper HC, van Mechelen W. Prediction of cardiovascular disease risk factors later in life by physical activity and physical fitness in youth: general comments and conclusions. *Int J Sports Med* 2002;**23 Suppl 1**:S44-9.
36. **Koutedakis Y,** Bouziotas C. National physical education curriculum: motor and cardiovascular health related fitness in Greek adolescents. *Br J Sports Med* 2003;**37**(4):311-4.
37. **McGavock JM,** Torrance B, McGuire KA, Wozny P, Lewanczuk RZ. The relationship between weight gain and blood pressure in children and adolescents. *Am J Hypertens* 2007;**20**(10):1038-44.
38. **Monyeki MA,** Koppes LL, Monyeki KD, Kemper HC, Twisk JW. Longitudinal relationships between nutritional status, body composition, and physical fitness in rural children of South Africa: The Ellisras longitudinal study. *Am J Hum Biol* 2007;**19**(4):551-8.

39. **Garnett SP,** Baur LA, Srinivasan S, Lee JW, Cowell CT. Body mass index and waist circumference in midchildhood and adverse cardiovascular disease risk clustering in adolescence. *Am J Clin Nutr* 2007;**86**(3):549-55.

40. **Juonala M,** Jarvisalo MJ, Maki-Torkko N, Kahonen M, Viikari JS, Raitakari OT. Risk factors identified in childhood and decreased carotid artery elasticity in adulthood: the Cardiovascular Risk in Young Finns Study. *Circulation* 2005;**112**(10):1486-93.

41. **Juonala M,** Raitakari M, J SAV, Raitakari OT. Obesity in youth is not an independent predictor of carotid IMT in adulthood. The Cardiovascular Risk in Young Finns Study. *Atherosclerosis* 2006;**185**(2):388-93.

42. **van Lenthe FJ,** van Mechelen W, Kemper HC, Twisk JW. Association of a central pattern of body fat with blood pressure and lipoproteins from adolescence into adulthood. The Amsterdam Growth and Health Study. *Am J Epidemiol* 1998;**147**(7):686-93.

43. **Sivanandam S,** Sinaiko AR, Jacobs DR, Jr., Steffen L, Moran A, Steinberger J. Relation of increase in adiposity to increase in left ventricular mass from childhood to young adulthood. *Am J Cardiol* 2006;**98**(3):411-5.

44. **Baker JL,** Olsen LW, Sorensen TI. Childhood body-mass index and the risk of coronary heart disease in adulthood. *N Engl J Med* 2007;**357**(23):2329-37.

45. **Lawlor DA,** Leon DA. Association of body mass index and obesity measured in early childhood with risk of coronary heart disease and stroke in middle age: findings from the aberdeen children of the 1950s prospective cohort study. *Circulation* 2005;**111**(15):1891-6.

46. **Lawlor DA,** Martin RM, Gunnell D, Galobardes B, Ebrahim S, Sandhu J, et al. Association of body mass index measured in childhood, adolescence, and young adulthood with risk of ischemic heart disease and stroke: findings from 3 historical cohort studies. *Am J Clin Nutr* 2006;**83**(4):767-73.

47. **Oren A,** Vos LE, Uiterwaal CS, Gorissen WH, Grobbee DE, Bots ML. Change in body mass index from adolescence to young adulthood and increased carotid intima-media thickness at 28 years of age: the Atherosclerosis Risk in Young Adults study. *Int J Obes Relat Metab Disord* 2003;**27**(11):1383-90.

48. **Franks PW,** Hanson RL, Knowler WC, Moffett C, Enos G, Infante AM, et al. Childhood predictors of young-onset type 2 diabetes. *Diabetes* 2007;**56**(12):2964-72.

49. **Eisenmann JC,** Wickel EE, Welk GJ, Blair SN. Relationship between adolescent fitness and fatness and cardiovascular disease risk factors in adulthood: the Aerobics Center Longitudinal Study (ACLS). *Am Heart J* 2005;**149**(1):46-53.

50. **Raitakari OT,** Juonala M, Viikari JS. Obesity in childhood and vascular changes in adulthood: insights into the Cardiovascular Risk in Young Finns Study. *Int J Obes (Lond)* 2005;**29 Suppl 2**:S101-4.

51. **Gunnell DJ,** Frankel SJ, Nanchahal K, Peters TJ, Davey Smith G. Childhood obesity and adult cardiovascular mortality: a 57-y follow-up study based on the Boyd Orr cohort. *Am J Clin Nutr* 1998;**67**(6):1111-8.

52. **Must A,** Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents. A follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med* 1992;**327**(19):1350-5.

53. **Bjorge T,** Engeland A, Tverdal A, Smith GD. Body mass index in adolescence in relation to cause-specific mortality: a follow-up of 230,000 Norwegian adolescents. *Am J Epidemiol* 2008;**168**(1):30-7.

54. **Engeland A,** Bjorge T, Sogaard AJ, Tverdal A. Body mass index in adolescence in relation to total mortality: 32-year follow-up of 227,000 Norwegian boys and girls. *Am J Epidemiol* 2003;**157**(6):517-23.

55. **Kujala UM,** Salminen JJ, Taimela S, Oksanen A, Jaakkola L. Subject characteristics and low back pain in young athletes and nonathletes. *Med Sci Sports Exerc* 1992;**24**(6):627-32.

56. **Barnekow-Bergkvist M,** Hedberg GE, Janlert U, Jansson E. Determinants of self-reported neck-shoulder and low back symptoms in a general population. *Spine* 1998;**23**(2):235-43.

57. **Burton AK,** Clarke RD, McClune TD, Tillotson KM. The natural history of low back pain in adolescents. *Spine* 1996;**21**(20):2323-8.

58. **Mikkelsson L,** Kaprio J, Kautiainen H, Kujala U, Mikkelsson M, Nupponen H. School fitness tests as predictors of adult health-related fitness. *Am J Hum Biol* 2006;**18**(3):342-9.

59. **Hestbaek L,** Leboeuf-Yde C, Kyvik KO. Are lifestyle-factors in adolescence predictors for adult low back pain? A cross-sectional and prospective study of young twins. *BMC Musculoskelet Disord* 2006;**7**:27.

60. **Mikkelsson LO,** Nupponen H, Kaprio J, Kautiainen H, Mikkelsson M, Kujala UM. Adolescent flexibility, endurance strength, and physical activity as predictors of adult tension neck, low back pain, and knee injury: a 25 year follow up study. *Br J Sports Med* 2006;**40**(2):107-13.

61. **Schmalz DL,** Deane GD, Birch LL, Davison KK. A longitudinal assessment of the links between physical activity and self-esteem in early adolescent non-Hispanic females. *J Adolesc Health* 2007;**41**(6):559-65.

62. **Ruiz JR,** Rizzo NS, Hurtig-Wennlöf A, Ortega FB, Wärnberg J, Sjöström M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. *Am J Clin Nutr* 2006;**84**(2):299-303.

63. **Gutin B,** Yin Z, Humphries MC, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *Am J Clin Nutr* 2005;**81**(4):746-50.

64. **Pfeiffer K,** Lobelo F, Ward DS, Pate RR. Endurance trainability of Children and Youth. In: The Young Athlete. *Encyclopaedia of sports medicine*; v. 13 (Hebestreit H and Bar-Or, O., ed) Blackwell Publishing, Oxford. In press. p. 84-95.

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 one 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

Table 2. List of included longitudinal studies with quality scores with reference to predictive value of physical fitness for cardiovascular disease 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
Hasselstrøm 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
Pietiläinen 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
Bjørge 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 & 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 cardiovascular disease risk factors and disease in children and adolescents.

Fitness component	Author/*Study* Quality score	Years of follow up	Subjects	Age	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 y	Boys = 36 Girls = 12	15.9 y to 27.2 y	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	Boyd 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 to 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 y 2004-2006	2089	5-19 y to 7-21 y	20mSRT (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 systolic BP over time. Specifically, systolic BP 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 systolic BP
Cardiorespiratory, motor and musculoskeletal fitness	Monyeki et al.[38] *The Ellisras Longitudinal Study*	1 y 2001-2002	Boys = 380 Girls = 322	7-14 y to 8-15 y	1600m run, standing broad jump, bent arm hang, sit ups, 4x5m shuttle run, and 50m 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-adolescence and adolescence

	Quality score=2						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 y 1980 2001/2002	 3596 2283	 3-18 y 24-39 y	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 y 1983 1991	Boys = 133 Girls = 172 Boys = 98 Girls = 137	16-19 y to 24-27 y	Maximal cycle ergometer test (measured VO_{2max} expressed as L/min, and L/kg/min)	TG, TC/HDLc, systolic BP, 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	Hasselstrøm et al.[18] *Danish youth and sports study*	8 y 1983	Boys = 133 Girls = 132	15-19 y to	Maximal cycle ergometer test (measured VO_{2max} expressed as mL/kg/min). Isometric	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 ($P<0.05$).

	Quality score=3	1991	Boys = 45 Girls = 57	23-27 y	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)		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, systolic BP, %BF, and risk score ($P<0.05$). Muscular strength was not associated with any of the outcome measures in girls
Cardiorespiratory fitness	Psarra et al.[21] Quality score=3	2 y 2000/2001 2002/2003	Boys = 477 Girls = 441	6-12 y to 8-14 y	20mSRT (number of completed laps)	BMI, WC, W/H, and %BF estimated using an electronic body composition analyzer (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 y 1977-1991	181	13 y to 27 y	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, systolic BP, diastolic BP, 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 systolic and diastolic BP 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 y	783	13-17 y to 27-31 y	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, systolic and diastolic BP, lipid profile, insulin, and glucose as compared with the lean individuals ($P<0.01$ to <0.001). The prevalence of clinically recognized hypertension and dyslipidemia increased 8.5-fold and 3.1- 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 systolic blood pressure occurred only among the overweight individuals (P<0.001)
Cardiorespiratory and musculoskeletal fitness	Barnekow-Bergkvist et al.[23] Quality score=4	18 y 1974 1992	Boys = 220 Girls = 205 Boys = 157 Girls = 121	15-18 y 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: Number of sit-ups and the number 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 systolic BP	Boys and Girls CRF at the age of 16 was not associated with any of the outcomes measures at the age of 34 y. Bench-press was negatively associated with BMI in males, whereas two-hand lift was negatively associated with BMI in females
Cardiorespiratory fitness	Boreham et al.[26] *The Northern Ireland Young Hearts Project* Quality score=4	8 y	Boys = 251 Girls = 203	12-15 y to 20-25 y	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 (i.e., not confounded nor mediated by) lifestyle variables, BF, and physical activity
Body composition	Garnett et al.[39] Quality score=4	7 y	342 290	7 y to 14 y	BMI, and WC	CVD risk clustering	Boys and Girls Children who were overweight or obese at 8 y of age were 7 times (OR: 6.9; 95% CI: 2.5, 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 y were 4 times (95% CI: 3.6; 1.0, 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 y	Boys = 63 Girls = 62	10.5 y to 15 y	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 systolic BP, sum of six skinfolds and WC (P<0.05) after controlling for age, gender, FFM, and pubertal status
Cardiorespiratory fitness	Johnson et al.[24] Quality score=4	3-5 y	White boys = 17 White girls = 55 Black boys = 19 Black girls = 24	4.6-11 y to 8-16 y	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 to 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 y 1990-1996	Boys = 212 Girls = 177	7-10 y to 14-17 y	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 odds ratio for metabolic syndrome during adolescence comparing the low vs high VO2max was not significant (P<0.07); however, when the low CRF

							(mL/kg^{FFM}/min) was compared to the moderate (second third), the odds ratio was significant (P<0.03)
Self-perceived physical fitness	Pietiläinen et al.[17] Quality score=4	4 y 1975-1979	4840 (including 1870 twins pairs)	16-18 y to 22-27 y	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 for adult overall (5.1, 95% CI: 2.0-12.7) and abdominal obesity (3.2, 95% CI: 1.5-6.7). 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 y 1985/1986 1992/1993 2000/2001	Men = 2029 Women = 2458 2478 3550	18-30 y to 43-45 y	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 hypercholesterolemia	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 hypercholesterolemia was modest (HR, 1.4; 95% CI, 1.1-1.7; 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, 0.2-1.0; P=0.04) and the metabolic syndrome (HR, 0.5; 95% CI, 0.3-0.7; 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 y 1989/90 - 1992/93 - 1997/99	Boys = 229 Girls = 230	12 and 15 y to 22.5 y	20mSRT (number of completed laps)	TC, HCLc, BP, sum of four skinfolds	Boys CRF changes were modestly and negatively associated with TC, HDLc, and systolic BP (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 diastolic BP (P=0.03)
Cardiorespiratory fitness	Byrd-Williams et al.[34] *Study of Latino Adolescents at Risk* Quality score=5	4 y 2001-2005	Boys = 84 Girls = 76	11 y to 15 y	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 (β= -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 (β=0.0005, P=0.37)
Cardiorespiratory fitness	Ferreira et al.[31] *The Amsterdam Growth and Health Longitudinal Study* Quality score=5	24 y	Boys = 75 Girls = 79	13-16 y to 36 y and 21-26 y to 36 y	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 From childhood to age 36: CRF (ml/min/kg$^{2/3}$) changes were not associated with carotid IMT. From adolescence to age 36: CRF was positively and significantly associated with carotid distension (P=0.015). This led to a positive and significant association between changes in CRF and carotid distensibility (P=0.020) and compliance (P=0.037). However, after adjustment for potential confounders, the associations with distension and distensibility decreased and were no longer

							significant, whereas those with carotid compliance remained significant (P=0.039)
Cardiorespiratory fitness and body composition	Ferreira et al.[33] *The Amsterdam Growth and Health Longitudinal Study* Quality score=5	23 y 1977-1991	Boys = 175 Girls = 189	13 y to 36 y	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 y three-time-point	210 204 198	12.3 y 13.3 14.3 y	20mSRT (estimated VO_{2max} (expressed as mLkg/min)	%BF estimated from skinfolds (triceps and medial calf)	Boys and Girls VO_{2max} was inversely associated with changes in BF (□=-0.09; P≤0.05)
Cardiorespiratory, motor and musculoskeletal fitness	Twisk et al.[28] *The Amsterdam Growth and Health Longitudinal Study* Quality score=5	20 y 1985 1996/1997	Boys = 132 Girls = 145 Boys = 80 Girls = 96	13 y to 32 y 13-16 y to 32 y	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, systolic BP, diastolic BP, sum of four skinfolds, and W/H	Boys and Girls CRF (expressed as mL/kg/min) in 13-16 years old group was negatively associated with sum of skinfolds, TC/HDLc and with systolic BP at 32 years of age in males and females CRF (expressed as mL/min) was negatively associated with BP in males, TC, sum of four skinfolds, and W/H (P<0.05) CRF (expressed as maximal slope) in 13 years old group was negatively associated with sum of skinfolds, and TC at 32 years of age in males and females Neuromotor fitness was positively related to systolic blood pressure (□=0.11; P<0.01) and inversely to the sum of four skinfolds (□=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 y 1955/1960	Boys = 139857 Girls = 136978	7-13 y to ≥23 y	BMI	CHD events	Boys and Girls The risk of any CHD event, a nonfatal event, and a fatal event among adults was positively associated with BMI at 7 to 13 years of age for boys and 10 to 13 years of age for girls. Adjustment for birth weight strengthened the results
Body composition	Bjørge et al.[53] Quality score=5	34.9 y	226682	14-19 y to 58-63 y	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 y	227003	14-19 y to 45-50 y	BMI	Mortality	An increasing risk of death by increasing BMI in adolescence was observed. Mortality among males 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 females were 30% and 100%
Body composition	Franks et al.[48]	~ 9 y	1604	5-19 y	BMI, and WC	Incidence of type 2 diabetes	Boys and Girls

	Quality score=5			to 14-28 y			In 5 to 9 y old subjects, WC was the strongest and single significant modifiable predictor of diabetes. In 10- to 14-year-old subjects, the strongest independent modifiable predictors were 2-h glucose, BMI, and A1C, whereas in the 15 to 19 y old subjects, the strongest predictors were 2-h glucose, WC, and A1C. When the age groups were combined (i.e. 5-19 y) 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 y	Boys = 1165 Girls = 1234	2-14 y to 59-71 y	BMI	Mortality	Boys and Girls All-cause and cardiovascular mortality were associated with higher childhood BMIs. Compared with those with BMIs between the 25th and 49th centiles, the hazard ratio (95% CI) for all-cause mortality in those above the 75th BMI centile for their age and sex was 1.5 (1.1, 2.2) and for ischemic heart disease it was 2.0 (1.0, 3.9). There was also a suggestion of a nonlinear 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 y	1081	3-18 y to 24-39 y	BMI	Carotid artery ITM, and obesity	Boys and girls Being overweight or obese in adolescence carried about four-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 to subjects who had been lean in youth. Subjects who had been obese in the youth but were non-obese as adults had comparable IMT values than 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 y	2255	10.7 y to 37.1 y	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 & Leon[45] *Aberdeen Children of the 1950s Prospective Cohort Study* Quality score=5	23 y 1981-2004	11106	4.9 y to 28 y	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, number of siblings, and birth weight) hazards ratio 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 y ~1988-2004	*Boyd Orr cohort* Boys = 1344 Girls = 1242 *Christ's Hospital* Boys = 1440 *Glasgow Alumni* Boys = 2637 Girls = 7918	2-15 y 9-18 y 16-22 y	BMI	Risk of adult ischemic heart disease and stroke	Boys and Girls BMI was not associated with future risk of ischemic heart disease or stroke in any cohort. The pooled (all 3 cohorts) adjusted hazard ratio per SD of early life BMI was 1.09 (95% CI: 1.01, 1.19) for ischemic heart disease and 0.94 (95% CI: 0.82, 1.08) for stroke. The pooled hazard ratio of ischemic 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
Body composition	Must et al.[52] Quality score=5	~ 60 y 1922/1935 1988	508	13-18 y to 73-78 y	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 coronary heart disease. The risk of morbidity from coronary heart disease 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 y	750	12-16 y to 27-30 y	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 to those who showed relative weight loss over time

Body composition	Raitakari et al.[4] *Cardiovascular Risk in Young Finns Study* Quality score=5	21 y 1980 2001/2002	3596 2283	3-18 y 24-39 y	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- to 18-year-old adolescents was directly related to carotid IMT measured in young adults at ages 33 through 39 years (*P*<.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 y 1977-1991	Boys = 84 Girls = 98	13-27 y to 36-50 y	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 systolic BP. After adjustment for sum of skinfolds and the behavioural variables (physical activity, smoking, and alcohol intake), the association remained statistically significant. In males, the increase of the S/T was significantly associated with decrease in TC level. However, after adjustment for sum of skinfolds, this association no longer remained statistically significant. The increase in 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 y 1985/1986 1999/2000	231 132	13 y to 27 y	BMI, FFM, and BF (measured with DXA)	Left ventricular mass	Boys and Girls BMI at 13 years was highly correlated with left ventricular mass index at 13 and 27 years. The cross-sectional correlation of left ventricular mass

index and BMI at 13 years (r = 0.38, P<0.0001) had strengthened considerably by 27 years (r =0.55, P<0.0001).

A BMI increase >5.5 kg/m^2 from 13 to 27 years was associated with a significantly greater increase in the left ventricular mass index (P<0.0001) 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 left ventricular mass index to FFM was weaker than that of left ventricular mass index to BF

TC indicates total cholesterol; HDLc, high density lipoprotein cholesterol; LDLc, low density lipoprotein cholesterol; TG, triglycerides; BP, blood pressure; Lp(a), lipoprotein (a); apo: apolipoprotein; CVD, cardiovascular disease; CHD, coronary heart disease; CRF, cardiorespiratory fitness (also refers to VO_{2max}); 20mSRT; 20 meters shuttle run test; BMI, body mass index; WC, waist circumference; W/H, waist to hip ratio; %BF, percentage of body fat; S/T, subscapular/triceps skinfolds ratio; SS/SSF, subscapular plus supraespinale skinfold/ subscapular plus supraespinale lus biceps plus triceps skinfolds; IMT, intima media thickness; OR, odds ratio; HR, hazard ratio; DXA, dual energy X-ray absorptiometry; y, years.

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	Fitness test	Outcome variables	Results
High quality studies							
Musculoskeletal and body composition	Kujala et al.[55] Quality score=3	1 y	Boys = 58 Girls = 80	10.3-13.3 y 11-14 y	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 last 12 months (self-reported)	Boys and Girls 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] Quality score=4	18 y 1974 1992	Boys = 220 Girls = 205 Boys = 157 Girls = 121	16 y 34 y	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 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 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. 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 was associated with a significantly decreased risk of low back problems in adulthood in women
Musculoskeletal fitness	Burton et al.[57] Quality score=4	5 y 1985-1990	216	11 y to 16 y	Lumbar sagital flexibility, measured using the flexicurve technique	Incidence and life time prevalence of low back pain (self-reported)	Boys and Girls 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] Quality score=5	25 y 1976-2001	Boys = 801 Girls = 886	12-17 y to 37-42 y	BMI, sit and reach, and 30 seconds 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 both boys and 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). 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] Quality score=5	8 y 1994-2002	9600 twins	12-22 y to 20-26 y	BMI	Number of days with low back pain during the past year at baseline in 1994 and at follow-up in 2002	Boys and Girls No associations were observed between adolescent overweight and adult low back pain

BMI indicates body mass index; BF, body fat; OR, odds ratio; CI, confidence interval.

- **Cardiorespiratory component**
  - Submaximal exercise capacity
  - Maximal aerobic power
  - Heart functions
  - Lung functions
  - Blood pressure
- **Musculoskeletal component**
  - Power
  - Strength
  - Endurance
  - Flexibility
- **Morphological component**
  - Body mass index
  - Body composition
  - Subcutaneous fat distribution
  - Abdominal visceral fat
  - Bone density
- **Motor component**
  - Agility
  - Balance
  - Coordination
  - Speed of movement

Figure 1.

SUPPLEMENTARY MATERIAL

Definitions

Predictive validity

Predictive validity is the extent to which a test predicts selected outcomes. In the present article, predictive validity refers to the question whether low/high physical fitness (exposure) predicts future disease/better health status (outcome).

Physical fitness and health-related physical fitness

There is no universal agreement upon definition of fitness and of its components, and it is one of the most poorly defined and most frequently misused terms in English literature. The present article relays to the following definition of physical fitness: "Physical fitness is a set of attributes that people have or achieve that relates to the ability to perform physical activity".[1]

Physical fitness is typically defined with focus on two goals: performance or health.

Performance-related fitness refers to those components of fitness that are necessary for optimal work or sports performance.[2] This is defined in terms of the individual's ability in athletic competition, a performance test or occupational work. Performance-related fitness depends heavily on aerobic and/or anaerobic capacity, muscular strength, power, endurance, body size, body composition, motivation, and nutritional status.

Health-related physical fitness consists of those components of physical fitness that have a relationship with health. These components are favourably or unfavourably affected by physical activity habits and are related to the health status. Health-related fitness has been characterized by an ability to perform daily activities with vigour, and by traits and capacities that are associated with a low risk for the development of chronic diseases and premature death.

The present manuscript focuses on the importance of assessing health-related fitness in children and adolescents. The health-related fitness components and factors/traits are depicted in Figure 1.

Health-related fitness components

Cardiorespiratory fitness: is a direct marker of physiological status and reflects the overall capacity of the cardiovascular and respiratory systems to supply oxygen during sustained physical activity, as well as the ability to carry out prolonged exercise.[3] The maximal oxygen consumption (VO_{2max}) attained during a graded maximal exercise is considered to be an objective measure of the cardiorespiratory fitness performance.[3]

Cardiorespiratory fitness, cardiovascular fitness, cardiorespiratory endurance, aerobic fitness, aerobic capacity, aerobic power, maximal aerobic power, aerobic work capacity, physical work capacity, and VO_{2max}, all refer to the same concept and are used interchangeably in the literature. In this review, only the term cardiorespiratory fitness is used. [4]

Musculoskeletal fitness: Balanced, healthy functioning of the musculoskeletal system requires that a specific muscle or muscle group be able to generate force or torque (measured as strength), to resist repeated contractions over time or to maintain a maximal voluntary contraction for a prolonged period of time (measured as muscular endurance), and to carry out a maximal, dynamic contraction of a single muscle or muscle group in a short period of time (measured as explosive strength, also called power).

Flexibility is another factor of the musculoskeletal component. It is the ability of a specific muscle or muscle group to move freely through a full range of motion. It is of importance in a variety of athletic performances but also in the capacity to carry out the activities of daily living, which is very important from a public health perspective.

Motor fitness: Motor fitness (also called skill-related physical fitness) consists of those components of physical fitness that have a relationship with enhanced performance in sports and motor skills. People with a good level of motor-related fitness will be more likely to engage in regular physical activity and for this reason may have enhanced health-related fitness. Motor-related fitness components are assessed with performance measures. Such components, as speed, are considered to be more related to heredity than healthy lifestyles, especially in children.

Morphological fitness: Morphological fitness relates to the relative amount of muscle, fat, bone and other vital parts of the body. According to the Bouchard's definition,[5] body composition is a factor of the morphological fitness, however, these terms are used interchangeably in the literature. In fact, the measures used to assess body composition are the same than those to assess morphological fitness. These measures include body mass index, waist circumference, waist to hip ratio, skinfold thickness. The term body composition will be used in the present article.

REFERENCES

1. **U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES**. Physical Activity and Health: A Report of the Surgeon General. Atlanta.GA: U.S. Department of Health and Human Services, Centres for Disease Control and Prevention, National Centre for Chronic Disease Prevention and Health Promotion. (http://www.cdc.gov/nccdphp/sgr/sgr.htm, accessed 11 March 2008).

2. **Bouchard C**, Sheppard RJ. *Physical activity, fitness, and health: the model and key concepts*: In: Bouchard C, Shephard RJ, Stephens T (eds.) Physical activity, fitness, and health. Champaign, IL: Human Kinetics Books, 1994: 77-88.

3. **Taylor HL,** Buskirk E, Henschel A. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J Appl Physiol* 1955;**8**(1):73-80.

4. **Ruiz JR,** Ortega FB, Gutierrez A, Meusel D, Sjöström M, Castillo MJ. Health-related fitness assessment in childhood and adolescence; A European approach based on the AVENA, EYHS and HELENA studies *J Public Health* 2006;**14**:269-277.

5. **Bouchard C**, Blair SN, Haskell WL. *Why study physical activity and health?*: In: Bouchard C, Blair SN, Haskell WL (eds.) Physical activity and health. Champaign, IL: Human Kinetics Books, 2007:3-22.