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PEDIATRIC REVIEW

Physical fitness in childhood and adolescence: a powerful marker of health

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This review aims to summarize the latest developments with regard to physical fitness and several health outcomes in young people. The literature reviewed suggests that (1) cardiorespiratory fitness levels are associated with total and abdominal adiposity; (2) both cardiorespiratory and muscular fitness are shown to be associated with established and emerging cardiovascular disease risk factors; (3) improvements in muscular fitness and speed/agility, rather than cardiorespiratory fitness, seem to have a positive effect on skeletal health; (4) both cardiorespiratory and muscular fitness enhancements are recommended in pediatric cancer patients/survivors in order to attenuate fatigue and improve their quality of life; and (5) improvements in cardiorespiratory fitness have positive effects on depression, anxiety, mood status and self-esteem, and seem also to be associated with a higher academic performance. In conclusion, health promotion policies and physical activity programs should be designed to improve cardiorespiratory fitness, but also two other physical fitness components such us muscular fitness and speed/agility. Schools may play an important role by identifying children with low physical fitness and by promoting positive health behaviors such as encouraging children to be active, with special emphasis on the intensity of the activity.
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Introduction

Physical fitness can be thought of as an integrated measure of most, if not all, the body functions (skeletomuscular, cardiorespiratory, hematocirculatory, psychoneurological and endocrine–metabolic) involved in the performance of daily physical activity and/or physical exercise. Hence, when physical fitness is tested, the functional status of all these systems is actually being checked. This is the reason why physical fitness is nowadays considered one of the most important health markers, as well as a predictor of morbidity and mortality for cardiovascular disease (CVD) and for all causes.[1–4] Physical fitness is in part genetically determined, but it can also be greatly influenced by environmental factors. Physical exercise is one of the main determinants.

Childhood and adolescence are crucial periods of life, since dramatic physiological and psychological changes take place at these ages. Likewise, lifestyle and healthy/unhealthy behaviors are established during these years, which may influence adult behavior and health status. Thorough reviews have recently discussed the associations between physical activity at young ages and its short/long-term consequences on health.[5–10] However, less is known about physical fitness and health outcomes in young people.[9] In the last years, an increasing amount of research on physical fitness and health in childhood and adolescence has been published.

This review aims to summarize the latest developments with regard to physical fitness and health outcomes such as adiposity, CVD risk factors, skeletal health, cancer and mental health, in young people.

Definitions and basic methodological issues

Physical fitness, physical exercise and physical activity are sometimes used as interchangeable concepts in the literature, which is not always appropriate.[11,12]

Physical fitness is the capacity to perform physical activity, and makes reference to a full range of physiological and psychological qualities. *Physical activity* is any body

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movement produced by muscle action that increases energy expenditure, whereas *physical exercise* refers to planned, structured, systematic and purposeful physical activity. In this review we will discuss the three main health-related physical fitness components: cardiorespiratory fitness, muscular fitness and speed/agility.

Cardiorespiratory fitness, also called cardiovascular fitness or maximal aerobic power, is the overall capacity of the cardiovascular and respiratory systems and the ability to carry out prolonged strenuous exercise. The maximal oxygen consumption (VO_{2max}) attained during a graded maximal exercise to voluntary exhaustion has long since been considered by the World Health Organization as the single best indicator of cardiorespiratory fitness.[13] Although different ways have been used to express VO_{2max}, the most common way is as the volume of oxygen consumed per unit of time relative to body mass ($ml\,min^{-1}\,kg^{-1}$ of body mass). However, researchers aiming to compare cardiorespiratory fitness level between groups of young people should care the way in which the VO_{2max} is expressed (that is, $ml\,min^{-1}\,kg^{-1}$ of body mass or $ml\,min^{-1}\,kg^{-1}$ of fat-free mass or $l\,min^{-1}$), since it can influence the results and interpretation, leading to misleading conclusions (Figure 1).[14]

The VO_{2max} can be estimated using maximal or submaximal tests, by direct or indirect methods. The most commonly used tests are walking/running tests followed by cycling and step tests. In epidemiological studies involving young people, the most common test for assessing cardiorespiratory fitness has been the 20-m shuttle run test, or adaptations/modifications of this test.[15,16] The VO_{2max} can then be estimated from the score obtained in this test from equations.[17]

Muscular fitness is the capacity to carry out work against a resistance. Since the maximum force that can be generated depends on several factors (for example, the size and number of muscles involved, the proportion of muscle fibres called into action, the coordination of the muscle groups, etc.) there is no single test for measuring muscle strength. The main health-related muscular fitness components are maximal strength (isometric and dynamic), explosive strength, endurance strength and isokinetic strength.

The handgrip test is one of the most used tests for assessing muscular fitness in epidemiological studies. In adults, handgrip strength has been reported to be a strong predictor of morbidity and life expectancy.[4] Due to its importance for health, we have carried out methodological investigations in order to increase the accuracy of measurement in both adults[18] and young people.[19] There is an optimal grip span to which the standard dynamometer should be adjusted when measuring handgrip strength in both male and female adolescents. In both genders, the optimal grip span is influenced by the hand size, which implies the need for adjustment of the grip span of the dynamometer to the hand size of the individual. For this reason, sex-specific equations are proposed to determine the appropriate grip span:[19]

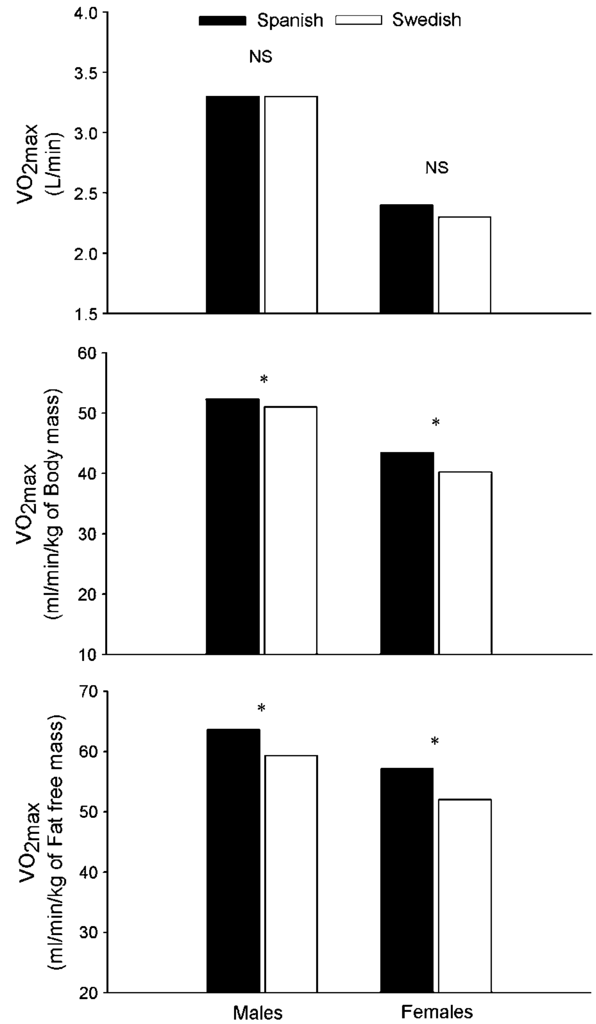

Figure 1 The choice of expression of VO_{2max} may affect the results and interpretation when comparing groups of adolescent people (data from the EYHS and AVENA studies; Ortega *et al.*[14]). * Indicates significant differences. AVENA, Alimentación y Valoración del Estado Nutricional de los Adolescents [Food and Assessment of the Nutritional Status of Spanish Adolescents]; EYHS, European Youth Heart Study; NS, not significant; VO_{2max}, maximal oxygen consumption.

$$\text{Males}: y = x/7.2 + 3.1 (r = 0.92; P = 0.01)$$

$$\text{Females}: y = x/4 + 1.1 (r = 0.93; P = 0.02)$$

where x is the hand size (maximal width between the thumb and small finger, with 0.5-cm precision), and y is the optimal grip span in cm.

Finally, jump tests, either a vertical jump test or a standing broad jump test, and the bent-arm hang test, have been widely used in young people for assessing explosive strength and endurance strength, respectively.[16,20]

Speed/agility: Speed is the ability to move the body (or some parts of the body) as fast as possible. Agility is the ability to move quickly and change direction while maintaining control and balance. Consequently, agility is a combination of speed, balance, power and coordination. The 30-m sprint test and the 4×10-m shuttle run test are useful tests for assessing speed and/or agility, respectively, in young people.[16,20] Several other tests have been proposed, but sufficient supporting literature for them is still lacking. Further methodological research is still needed for a better understanding of the accuracy, validity and reliability of the available fitness tests.

Physical fitness and health outcomes

Physical fitness and adiposity
The number of investigations into overall obesity and abdominal obesity (also called central obesity) and physical fitness has increased substantially in the last years.

Physical fitness and total adiposity. Data from the Swedish part of the European Youth Heart Study (EYHS), a school-based, cross-sectional study of risk factors for future CVD in a random sample of children (9–10 years old) and of adolescents (15–16 years old),[21] indicate that those individuals having a high cardiorespiratory fitness level also have significantly lower total adiposity, as measured by skinfold thicknesses (Figure 2).[22] When total fatness was assessed by a reference method, that is, Dual Energy X-ray Absorptiometry, a similar inverse association was found in Spanish[24] and North American[25] children. Cardiorespiratory fitness has shown a stronger association with total adiposity, as measured by skinfold thicknesses, than other physical fitness components such as muscular fitness, speed/agility, flexibility or motor coordination.[26] Even in overweight or obese children, those children who had a higher cardiorespiratory fitness have shown a lower overall adiposity.[27] Longitudinal data have shown a significant relationship between adolescent cardiorespiratory fitness and later body fatness.[28,29]

Physical fitness and abdominal adiposity. Abdominal obesity seems to be a better predictor than overall obesity for the risk of CVD and type II diabetes, as well as being a strong predictor of morbidity and mortality in adults, independently of body mass index.[30] In population studies, waist circumference has shown to be an accurate measurement for intra-abdominal and subcutaneous fat, measured by magnetic resonance imaging, in children and adolescents.[31]

Data from the Alimentación y Valoración del Estado Nutricional de los Adolescents [Food and Assessment of the Nutritional Status of Spanish Adolescents] (AVENA) study, a multicenter cross-sectional study carried out in 2859 Spanish adolescents,[32,33] show that both moderate to high levels of cardiorespiratory fitness are associated with lower abdominal

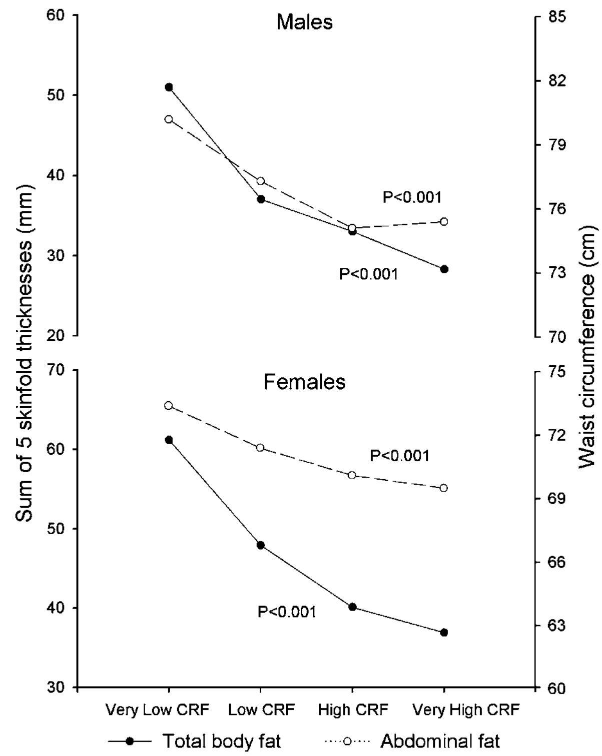

Figure 2 Association between cardiorespiratory fitness (CRF) and either total or abdominal adiposity in children and adolescents, after adjustment for age (data from the Swedish part of the EYHS and AVENA studies; Ruiz *et al.*[22] and Ortega *et al.*[23], respectively). AVENA, Alimentación y Valoración del Estado Nutricional de los Adolescents [Food and Assessment of the Nutritional Status of Spanish Adolescents]; EYHS, European Youth Heart Study.

adiposity (Figure 2).[23] These results are in accordance with those found in Irish children.[34] Similar associations have also been reported when physical fitness was measured as lower limb explosive strength, abdominal endurance strength or speed/agility instead of cardiorespiratory fitness.[35] In the previously mentioned studies, abdominal adiposity was assessed by measuring waist circumference. The same inverse association with cardiorespiratory fitness was observed when visceral and abdominal subcutaneous adipose tissue were measured using computed tomography or magnetic imaging resonance instead of waist circumference.[25,36] Further longitudinal investigations are needed for a better understanding of the specific associations of physical fitness with later abdominal adiposity and related diseases.

Physical fitness and CVD risk factors
Cardiovascular disease events occur most frequently during or after the fifth decade of life; however, there is evidence to indicate that the precursors of CVD have their origin in childhood and adolescence.[37] CVD risk factors such as total and high-density lipoprotein cholesterol (HDLc), low-density lipoprotein cholesterol (LDLc), triglycerides, insulin resistance, inflammatory proteins, blood pressure and body

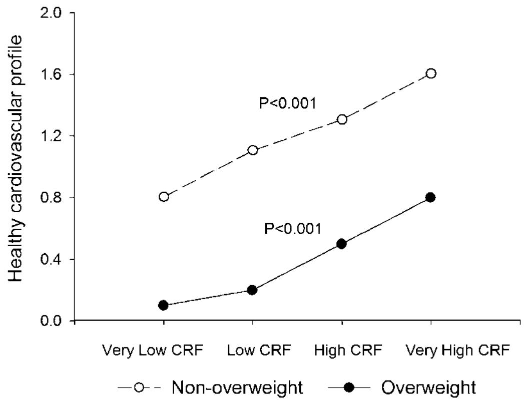

Figure 3 Association between cardiovascular profile (calculated from age- and gender-specific standardized values of triglycerides, LDLc, HDLc and fasting glycemia) and CRF quartiles in non-overweight and overweight Spanish adolescents. A higher score implies a healthier profile (data from the AVENA study; Castillo *et al.*[40]). AVENA, Alimentación y Valoración del Estado Nutricional de los Adolescents [Food and Assessment of the Nutritional Status of Spanish Adolescents]; CRF, cardiorespiratory fitness; HDLc, high-density lipoprotein cholesterol; LDLc, low-density lipoprotein cholesterol.

fat during childhood have been shown to track into adulthood.[38,39]

Cardiorespiratory fitness and CVD risk factors. We have shown that higher levels of cardiorespiratory fitness are inversely associated with a healthier cardiovascular profile in children and adolescents.[16,23,40–54] Results from the AVENA study indicate that high levels of cardiorespiratory fitness are associated with a more favorable metabolic profile (computed from age- and sex-specific standardized values of triglycerides, LDLc, HDLc and fasting glycemia) in both overweight and non-overweight Spanish adolescents (Figure 3).[52] The same association was also found between cardiorespiratory fitness and the clustering of metabolic risk factors and individual CVD risk factors in Swedish and Estonian children and adolescents participating in the EYHS.[43,47,51] Sex-specific cardiorespiratory fitness cut-off values associated with a healthier cardiovascular profile (below the 75th percentile of a computed risk score) were determined in school-aged children.[47] The cardiorespiratory fitness level associated with a low metabolic risk score was 37.0 and 42.1 $ml\,kg^{-1}\,min^{-1}$ in girls and boys, respectively. Therefore, low (high) cardiorespiratory fitness was defined when the cardiorespiratory fitness levels were <37.0 and 42.1 ($\geqslant 37.0$ and 42.1) $ml\,kg^{-1}\,min^{-1}$, in girls and boys, respectively. These cut-off values require further testing in other populations as well as in longitudinal and/or interventional studies.

There are reasons to believe that there might be potential interactions between cardiorespiratory fitness and fatness in relation to CVD risk.[44,49,51,55] Regarding cardiorespiratory fitness and traits of pediatric type II diabetes, data from the Swedish and Estonian part of the EYHS indicate that cardiorespiratory fitness explains a significant proportion of the homeostasis model assessment, a surrogate of insulin resistance, and fasting insulin variance in those children with relatively high levels (that is, the highest tertile) of body fat and waist circumference.[49] Data from the same study population show that markers of total and abdominal adiposity are related to blood pressure in girls with low levels of cardiorespiratory fitness.[44] Further analysis revealed that girls with hypertension had higher fatness and lower fitness compared with girls with normal blood pressure. Taken together, these findings suggest that the deleterious consequences ascribed to high fatness could be counteracted by having high levels of cardiorespiratory fitness. If so, it would imply that interventions to prevent states of unfavorable cardiovascular profile should focus not only on weight reduction but also on enhancing cardiorespiratory fitness.

Cardiorespiratory fitness has also been inversely associated with other CVD risk factors such as low-grade inflammatory markers and homocysteine in young people.[48,56,57] The levels of C-reactive protein and C3 were inversely associated with cardiorespiratory fitness in prepubertal children,[48] which is consistent with other studies of young people.[58–60] Halle *et al*.[59] reported that interleukin-6 levels were as low for obese and fit as for lean and unfit children, while the highest serum interleukin-6 concentrations were found in the obese and unfit group. Similarly, data from the AVENA study show that overweight and unfit adolescents are more likely to have high levels of C-reactive protein, C3 and C4 compared with non-overweight and fit peers.[57]

In adults, cardiorespiratory fitness has been inversely associated with relatively novel CVD risk factors such as homocysteine.[61] Studies examining the association between cardiorespiratory fitness and homocysteine levels in young people are scarce. We have found conflicting results in Spanish adolescents[50] and Swedish children and adolescents[62] after controlling for different potential confounders including age, puberty, birth weight, smoking, socioeconomic status, skinfold thickness and methylenetetrahydrofolate reductase 677C>T genotype. Cardiorespiratory fitness was inversely and significantly associated with homocysteine in female Spanish adolescents,[50] whereas no association was found in Swedish children and adolescents.[62] These results should encourage discussion on whether the metabolism of homocysteine could be one way in which the benefits of high cardiorespiratory fitness are exerted.

Muscular fitness and CVD risk factors. The role of muscular fitness in the performance of exercise and activities of daily living, as well as in preventing disease has become increasingly recognized.[63,64]

Data from the AVENA study show that there is an inverse association between muscular fitness, as defined by an index computed from the standardized scores of maximal handgrip strength, explosive strength and endurance strength, and a CVD risk score (an average value from the standardized triglycerides, LDLc, HDLc and glucose) in female adolescents.[54] In addition, it was reported that for a given

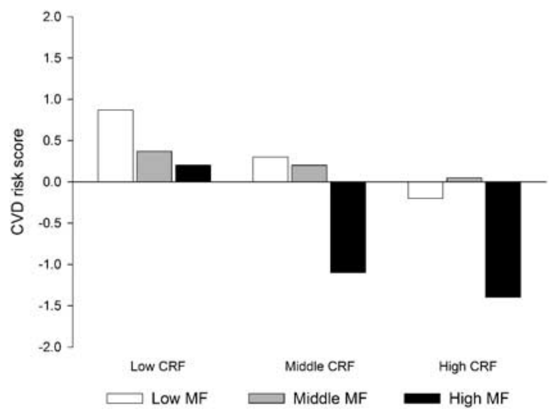

Figure 4 Associations between CVD risk score (an average value from the standardized triglycerides, LDLc, HDLc and glucose) and muscular fitness for a given level of CRF in adolescents. A higher score implies greater CVD risk. Data from the AVENA study, García-Artero *et al.*[54]. AVENA, Alimentación y Valoración del Estado Nutricional de los Adolescents [Food and Assessment of the Nutritional Status of Spanish Adolescents]; CRF, cardiorespiratory fitness CVD, cardiovascular disease; HDLc, high-density lipoprotein cholesterol; LDLc, low-density lipoprotein cholesterol; MF, muscular fitness.

cardiorespiratory fitness level, an increased level of muscular fitness was associated with a lower CVD risk score (Figure 4). These findings suggest that both cardiorespiratory and muscular fitness may have a combined and accumulative effect on the improvement of cardiovascular health in young people. Findings from the same cohort also indicate that muscular fitness is inversely associated with C-reactive protein, C3 and ceruloplasmin.[65] Further analysis revealed that C-reactive protein and transthyretin are also inversely associated with muscular fitness in overweight adolescents after controlling for different confounders, including cardiorespiratory fitness.[65]

Collectively, these findings support the concept that cardiorespiratory and muscular fitness may exert a positive effect on the cardiovascular system from an early age. In fact, due to this interest as a health marker for cardiovascular health status, we have suggested the inclusion of physical fitness testing in health monitoring systems.[45] Prospective studies are needed to examine the independent and joint effects of cardiorespiratory and muscular fitness in preventing the development of CVD risk factors among young people.

Physical fitness and skeletal health

Osteoporosis and related fractures are a current health concern worldwide and senile osteoporosis has been described as a ‘pediatric disease’,[66] as the accumulation of bone mass during childhood and adolescence may contribute more than half of the variability of bone mass with age.[67] Extra gains in bone mass during growth could be crucial to achieving a high peak bone mass and to preventing osteoporotic fractures later in life. In this regard, a systematic review focused on the associations between adolescent physical activity and several health outcomes concludes that there is a strong evidence indicating that adolescent physical activity is related to bone health at that age and also in later life.[5] However, the short-term and long-term relationships between physical fitness and skeletal health have not been specifically reviewed yet. Is physical fitness in young people associated with bone health at these ages and later in life? Which are the main physical fitness components that are related to bone health?

A cross-sectional study showed a positive association between total and site-specific bone mineral status and both cardiorespiratory and muscular fitness, in male adolescents.[68] In male and female adolescents from the AVENA study, the bone mineral content of the whole body was directly associated with physical fitness (that is, cardiorespiratory fitness, muscular fitness and speed/agility), and seemed to be mediated by the association between fitness and lean mass.[44] In fact, the results suggested that the bone mass differences between males and females could probably be explained by differences in physical fitness and lean mass.

A 3-year follow-up study carried out in Spanish prepubertal boys revealed that improvements in running speed (30-m sprint test) and explosive strength (vertical jump test), but not cardiorespiratory fitness, were associated with the enhancement of bone mass.[69] A 2-year longitudinal study reported that improvements in cardiorespiratory fitness predicted increased bone formation and bone resorption in female adolescents.[70] However, data from a 15-year follow-up study showed that during adolescence and young adulthood, only neuromotor fitness, as defined by muscular fitness and speed, and not cardiorespiratory fitness, was related to the bone mineral density at adulthood.[71] Similarly, a 20-year follow-up study showed that the main physical fitness component at adolescence related to adult bone mineral content was muscular fitness, although a significant correlation was also found between cardiorespiratory fitness and lumbar spinal bone mineral density.[72]

The physiological explanation of the findings mentioned above can be hypothesized. It has been reported that an increase in lean mass is the most important predictor of bone mineral mass accrual during prepubertal growth.[10] Since skeletal muscle is the primary component of lean mass, and improvements of muscular fitness accompanying muscular development would increase the generation of forces on bone attachment, indirectly stimulating bone growth.[73–75] Taking together the literature reviewed and the physiological rationale of the association between fitness and bone mass, seems more plausible that muscular fitness and speed/agility, rather than cardiorespiratory fitness, are independent predictors of bone mineral density. Finally, from a health promotion point of view it seems important to highlight that participation in sport and exercise should start before the pubertal growth spurt in order to achieve the maximum development of both bone mass and skeletal muscle development.[10]

Physical fitness and cancer

Cancer remains an important public health problem worldwide.[76] Leukemia is the most common childhood cancer and the leading cause of cancer death among children and adolescents. Since 75% of children with leukemia cancer have acute lymphoblastic leukemia, this section will describe the available literature on physical fitness and cancer, with special focus on acute lymphoblastic leukemia.

Poor physical fitness is largely responsible for the disrupting symptoms of fatigue that cancer patients/survivors experience during normal activities of daily living, with subsequent impairment in quality of life.[77] Cardiorespiratory fitness tends to be reduced in survivors of acute lymphoblastic leukemia.[78,79] This suggests the need for this population group to engage in regular physical activities, with the purpose of increasing their functional capacity or physical fitness. More recent data show that even 5–6 years after cessation of childhood leukemia treatment, there are still clear negative effects on motor performance and physical fitness.[80] Both chemotherapy-induced neuropathy and muscle atrophies are probably the prominent causes for this reduced physical fitness status.[80] Improvements in cardiorespiratory and muscular fitness through physical exercise have been indicated for patients surviving leukemia.[77] The effects of a 16-week intrahospital supervised conditioning program including both resistance and aerobic training on several fitness components in children receiving treatment for acute lymphoblastic leukemia were examined.[81] Young children in the maintenance phase of treatment against acute lymphoblastic leukemia can safely perform both aerobic and resistance training, attaining significant increases in cardiorespiratory fitness, muscular fitness and functional mobility. In addition, after 20 weeks without any training, strength and functional mobility were well maintained, whereas cardiorespiratory fitness measurements were only partially maintained. Even a period of time as short as 8 weeks seems to be enough to produce clinically relevant early-phase adaptations (that is, improved functional mobility and muscular fitness) and improvements in quality of life in children receiving treatment against acute lymphoblastic leukemia and children who have undergone bone marrow transplantation.[82,83] The experts highlight the potential health benefits of an enhanced physical fitness and well-being in survivors of cancer.[77,82,84] In this regard, Lucia *et al*.[85] have indicated that even although exercise training most likely will not improve survival rates, supervised exercise has the potential to considerably improve children's quality of life and overall health status during treatment periods.

Physical fitness and mental health

Mental health is how people think, feel and act as they face life's situations. Like adults, children and adolescents can have mental health disorders such as depression, anxiety or self-esteem. There is strong evidence suggesting that physical activity improves mental health in young people,[5] but the literature focused on the relationship between fitness and mental health is scarce.

Physical activity sessions of intensity sufficient to promote improvement in cardiorespiratory fitness seem to positively affect depression status and self-esteem, compared with a control group that worked at a lower intensity.[86] This suggests that the improvement of cardiorespiratory fitness is required for an enhanced psychological well-being. In this regard, the literature about young people is rather scarce, whereas some evidence has been shown in adults. DiLorenzo *et al*.[87] designed a thorough randomized controlled trial in order to examine the effects of increasing cardiorespiratory fitness, by means of an aerobic exercise program, on psychological outcomes (that is, depression, anxiety, mood status and self-concept). The study concluded that exercise-induced increases in cardiorespiratory fitness have beneficial short-term and long-term effects on all the psychological outcomes studied.

Possible explanations for the positive effects of physical fitness on psychological well-being are as follows:

(a) Increasing physical fitness via aerobic and resistance training is usually associated with a decrease in fat mass and an increase in lean mass. This is quite visible to individuals, leading to enhancement body image, which may explain some of the other improvements in psychological outcomes.
(b) Increased fitness may have a direct effect on neurochemicals in the brain such as serotonin or endorphins that function to elevate mood.

An interesting concept related to mental status is mental fitness or brain fitness, which refers to the cognitive performance of the individuals. Many studies have been conducted in adults to test the potentially beneficial effects of increases in cardiorespiratory fitness on cognition.[88] However, similar information in young people is lacking. Recently, it has been reported that physical fitness, especially cardiorespiratory fitness, seems to be positively related to academic performance (that is, mathematics, reading and overall performance) in youths.[89] Improvements in mental fitness at young ages could have many positive consequences for daily life activities in childhood and adolescence, as well as later in life. However, further research is still required in this emerging field.

Effects of physical activity and exercise on physical fitness

Cross-sectional studies using objectively measured physical activity

The apparently obvious association between cardiorespiratory fitness and physical activity still requires further research, mainly due to the complexity of assessing physical activity.[90,91] Efforts are being made in order to standardize and improve the assessment of physical activity and physical fitness in Europe (for example, the ALPHA study, Instruments for Assessing Levels of PHysical Activity and related health determinants).

Physical activity may have different effects on physical fitness depending on its intensity. We have observed that increased levels of vigorous physical activity (>6 metabolic equivalents), rather than light/moderate physical activity, are associated with a higher cardiorespiratory fitness level in children and adolescents.[22] Similar results have been reported by others.[34,92] This was also the case when cardiorespiratory fitness level was assessed by direct oxygen consumption.[93] In this context, we examined whether the adolescents who meet the current physical activity recommendations are more likely to have a high cardiorespiratory fitness level.[94] The results suggested that achieving 60 min or more of moderate–vigorous physical activity daily is associated with a healthier cardiorespiratory fitness level in adolescents, independently of their adiposity status.[95] The health level of cardiorespiratory fitness was established according to the cut-off values proposed by the Cooper Institute (for adolescent boys, this corresponds to a VO_{2max} of $42\,ml\,min^{-1}/kg^{-1}$, and for girls 14 years or older, to $35\,ml\,min^{-1}\,kg^{-1}$).[96,97]

Randomized controlled trials

Several randomized or clinical controlled trials have been conducted to study the effects of physical exercise programs on cardiorespiratory fitness and/or other physical fitness components, such as muscular fitness and speed/agility. In school-aged children, the results are consistent and show that different types of physical exercise programs (including or not diet intervention) are successful in improving cardiorespiratory fitness, as well as muscular fitness and speed/agility.[98–101] Although less studies have been conducted in preschool children ($\leqslant$6 years old), similar findings have been reported already at these ages.[99,102–104] Baquet *et al.*[105] have reviewed the available literature on endurance training and cardiorespiratory fitness in young people. They concluded that after rejection of all those studies that did not meet the high quality criteria (that is, the lack of a control group, an unclear training protocol, inappropriate statistical procedures, small sample size, studies with trained or special populations), endurance training leads to improvements of cardiorespiratory fitness in children at different ages, specially when high intensities ($\geqslant$80% of maximal heart rate) are achieved.

Regarding maturity development, to our knowledge no exercise training studies have comprehensively examined the 'trainability' (that is, the extent to which the physiologic markers of cardiorespiratory fitness change as a result of regular participation in endurance exercise) in children and adolescents in the three developmental stages (pre-pubescence, pubescence or circumpubertal stage and post-pubescence or adolescence). This is because most of the relevant studies have used chronologic age, and not developmental status, as the basis for categorizing the individuals. The available data from these studies do not indicate periods of enhanced aerobic trainability during childhood and/or youth.[105,106]

Moreover, the results have consistently shown no sex differences between the usefulness of physical training for improving cardiorespiratory fitness in boys and girls.[106]

To sum up, the available information from large-scale epidemiological studies using objective methods for assessing physical activity, and findings from randomized controlled trials, support that high-intensity physical activity is associated with physical fitness, and that properly designed and controlled physical exercise programs improve physical fitness in children and adolescents, independent of chronological age, maturation development and sex. High-intensity physical activity seems to be a key element for physical fitness enhancement.

Summary

The relationships between physical fitness and the health outcomes discussed here, indicating the main fitness components involved in these associations, are illustrated in Figure 5. There is strong evidence indicating that cardiorespiratory fitness levels are associated with *total and abdominal adiposity*, when adiposity is assessed either by anthropometric indexes or by reference methods such as Dual Energy X-ray Absorptiometry, computed tomography or magnetic resonance imaging.

Both cardiorespiratory and muscular fitness have shown to be associated with *traditional and emerging CVD risk factors*. The available information suggests that the deleterious consequences ascribed to high fatness could be counteracted by having high levels of cardiorespiratory fitness. In addition, both cardiorespiratory and muscular fitness seem to have a combined and accumulative effect on cardiovascular profile in young people.

Improvements in muscular fitness and speed/agility, rather than cardiorespiratory fitness, seem to have a positive effect on *skeletal health*. It is highly recommended to start participation in sports and exercise at prepubertal ages and to be maintained through the pubertal development in order to obtain the maximum benefit on bone mass.

Both cardiorespiratory and muscular fitness enhancements are recommended in pediatric *cancer* patients/survivors in order to compensate for the chemotherapy-induced neuropathy and muscle atrophies, to attenuate fatigue and to improve their quality of life.

The literature on the association between physical fitness and *mental health* in young people is still scarce. To date, the available information suggests that improvements in cardiorespiratory fitness have short-term and long-term positive effects on depression, anxiety, mood status and self-esteem in young people, being also associated with a higher academic performance.

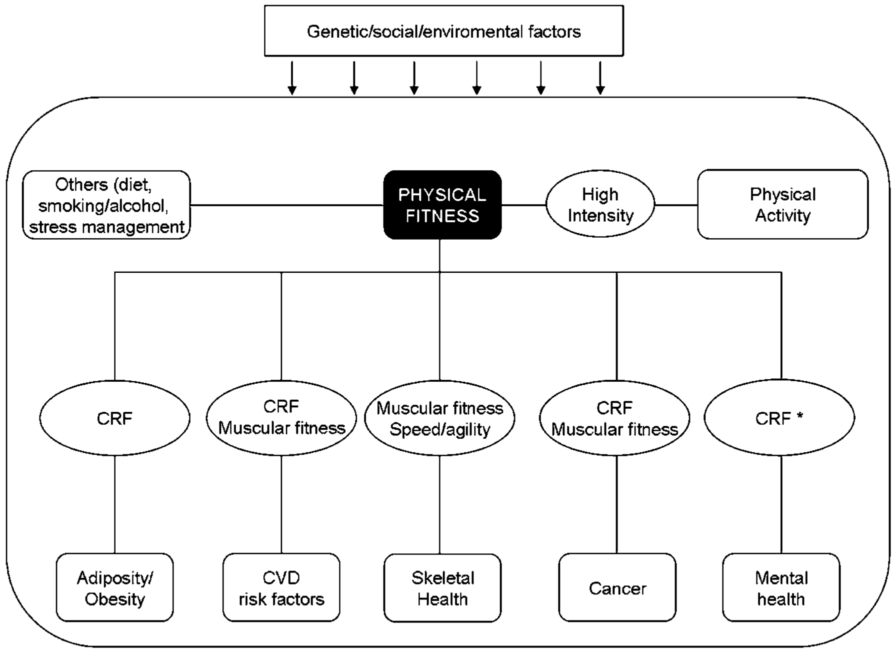

Figure 5 Associations between physical fitness and several health outcomes, showing the main health-related physical fitness components involved in those associations. * No information has been found about the other fitness components.

Conclusions

We conclude that:

(1) Physical fitness should be considered as a useful health marker already in childhood and adolescence, reinforcing the need to include physical fitness testing in health monitoring systems.
(2) Physical fitness enhancement, through increases in the time spent in vigorous physical activity and high-intensity training, should be a major goal in current and future public health promotion policies.
(3) Given that physical fitness components relate in different ways to the different health outcomes, physical activity programs should be designed to improve not only the levels of cardiorespiratory fitness but also muscular fitness and speed/agility. School may play an important role by helping to identify children with low physical fitness, and by promoting positive health behaviors such as encouraging children to be active, with special emphasis on the intensity of the activity. Longitudinal studies and randomized control trials are still needed in this field to understand the nature and relative importance of alternative determinants of physical fitness during growth and maturation, and to verify the usefulness of alternative promotion strategies and recommendations. Care must be taken not to base unrealistic aims for public health on tentative results and unattainable recommendations.

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