Circulation

AHA SCIENTIFIC STATEMENT

# Cardiorespiratory Fitness in Youth: An Important Marker of Health

## A Scientific Statement From the American Heart Association

**ABSTRACT:** Cardiorespiratory fitness (CRF) refers to the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production needed during physical activity. CRF is an important marker of physical and mental health and academic achievement in youth. However, only 40% of US youth are currently believed to have healthy CRF. In this statement, we review the physiological principles that determine CRF, the tools that are available to assess CRF, the modifiable and nonmodifiable factors influencing CRF, the association of CRF with markers of health in otherwise healthy youth, and the temporal trends in CRF both in the United States and internationally. Development of a cost-effective CRF measurement process that could readily be incorporated into office visits and in field settings to screen all youth periodically could help identify those at increased risk.

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Cardiorespiratory fitness (CRF) refers to the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production needed during physical activity.[1,2] Low or unhealthy CRF is a strong, independent predictor of cardiovascular disease (CVD) and all-cause mortality in adults.[1] In youth, CRF is a predictor of a number of health indicators, including cardiometabolic health,[3,4] premature CVD,[5] academic achievement,[6] and mental health.[4,7] Unfortunately, only 40% of 12- to 15-year-olds in United States currently are believed to have healthy CRF.[8] In addition, over the past 6 decades, CRF has declined, both in the United States and internationally.[9–11] Although the reasons for this decline are not well understood, an increase in obesity, increased sedentary time, decreased levels of moderate to vigorous physical activity, and social and economic changes may have contributed.[9,11]

Although CRF is assessed at times in certain youth such as those with congenital heart disease, asthma, and cystic fibrosis, assessment of CRF has a broader range of applications. CRF is an objective measure of health that can be tracked over time and compared across populations.[1,9] Whereas self-reported physical activity levels can be unreliable[12] and provide only a snapshot of behavior, assessments of CRF provide a more robust measure of cardiovascular health. Consistent with this sentiment, a recent American Heart Association statement suggests that CRF be assigned as a vital sign because it has the power to predict mortality in adults similar to traditionally assessed risk factors such as tobacco use, type 2 diabetes mellitus, hypertension, and hypercholesterolemia.[1]

The central focus of this statement is to raise clinicians' awareness of the importance of CRF in predicting current and future health in otherwise healthy

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youth, knowing that CRF measurements provide an objective measure of health as opposed to physical activity recall, which is the current practice. An explicit purpose of this statement is to explore valid, low-cost alternatives to traditional cardiopulmonary exercise tests (CPETs) to assess CRF in otherwise healthy youth in office settings with limited space that can be performed by personnel not formally trained in exercise physiology. This statement reviews current knowledge related to the association between CRF and health outcomes in youth, describes the added value of CRF to improve risk prediction, and highlights gaps for future research with the following areas addressed:

1. Physiological considerations
2. Various tests that can be used to assess CRF in the field and office settings
3. Key modifiable and nonmodifiable factors influencing CRF, including the effect of interventions
4. The impact of CRF on cardiovascular, cerebrovascular, cognitive, and mental health
5. Temporal trends in CRF in youth nationally and internationally
6. Knowledge gaps and suggestions for future research

This statement does not discuss special risk groups of youth such as those with unpalliated/palliated congenital heart disease.[13] Physical activity guidelines for youth are covered in detail in other documents[14]; discussion of these guidelines is limited. The focus of this statement is primarily to examine CRF in otherwise able and healthy, disease-free youth.



## HEALTH-RELATED FITNESS AND ASSOCIATED PHYSIOLOGICAL CHANGES

Although this statement focuses on CRF, this is only 1 of 4 distinct health-related fitness components. CRF, also known as cardiorespiratory endurance, cardiovascular fitness, aerobic capacity, and aerobic fitness, among others, refers to the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production during physical activity.[15] A second component, muscular fitness, is the ability of the body to exert maximal force against an external resistance (ie, muscular strength) or repeatedly under submaximal loads (ie, local muscular endurance). Third, flexibility refers to an individual's range of motion around a joint or group of joints. Flexibility is important for preventing musculoskeletal injury, maintaining functional independence, and performing sports and activities of daily living. The fourth component, body composition, is the relative proportion of total body mass composed of fat, fat-free tissue, and total body water.

Table 1 includes a summary of physical activity intensity categories for youth 8 to 18 years of age that are based on heart rate, maximum oxygen uptake, perceived exertion, and metabolic equivalent (MET).[20–23] Energy expenditure often is quantified as METs, with 1 MET equal to 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ (oxygen

**Table 1. Categories of Physical Activity for Youth 8 to 18 Years of Age**

| Intensity Category | Description | Example Activities | Measures (mean values for 8–18 y of age) |
|---|---|---|---|
| Sedentary | Waking behavior typically performed in a sitting, reclining, or lying posture | Sitting or reclining while watching television, playing video games, driving, reading, and fishing | <1.5 METs<br><40% $HR_{max}$<br><20% HRR<br><20% $\dot{V}o_2$max<br>RPE: <8 |
| Light | Light aerobic activity that does not cause a noticeable increase in breathing and can be sustained for at least 60 min | Domestic or occupational tasks such as washing dishes, ironing, working at a desk, or performing office duties | 1.5–4 METs<br>40%–63% $HR_{max}$<br>20%–39% HRR<br>20%–45% $\dot{V}o_2$max<br>RPE: 8–11 |
| Moderate | Aerobic activity that can be sustained while maintaining a conversation uninterrupted | Gentle swimming, social tennis, and golf | 4–6 METs<br>64%–76% $HR_{max}$<br>40%–59% HRR<br>46%–63% $\dot{V}o_2$max<br>RPE: 12–13 |
| Vigorous | Aerobic activity during which a conversation cannot be maintained; an intensity that may last up to 30 min | Jogging, aerobics, fast bicycling, resistance training, competitive sports | 6–9 METs<br>77%–95% $HR_{max}$<br>60%–89% HRR<br>64%–90% $\dot{V}o_2$max<br>RPE: 14–17 |
| Near maximal to maximal | Activity that typically cannot be sustained for >10 min | Sprinting, periods of competitive team sport activity | ≥ 9 METs<br>≥ 96% $HR_{max}$<br>≥ 90% HRR<br>≥ 91% $\dot{V}o_2$max<br>RPE: ≥18 |

Children undergo systematic changes in body composition as a result of growth and maturation, which have implications for activity intensity classifications. Thus, MET cut points should be adjusted for differences in resting energy expenditure. Youth METs have been adjusted to account for the unique physiological characteristics of children and adolescents.

HRR indicates heart rate reserve (HRR=$HR_{max}$−resting heart rate); $HR_{max}$, heart rate maximum ($HR_{max}$=220−age); MET, metabolic equivalent; RPE, Borg's Rating of Perceived Exertion scale (range, 6–20); and $\dot{V}o_2$max, maximum oxygen uptake.[16–19]

 The reported MET values in this table were derived from the Youth Compendium of Physical Activities for specific activities and adapted by Eather et al.[21]

**Table 2. Comparison of Selected Tests Used to Measure CRF***

| | Description | Ability to Assess CRF† | Limitations | Suggestions for Clinical Practice |
|---|---|---|---|---|
| CPET (gas analyzed) | Participants exercise with incrementally increasing difficulty/workload with $\dot{V}O_2$ measured via respiratory gases | +++ | Sophisticated equipment needed | Gold standard for measurement of $\dot{V}O_2$ |
| 20mSRT (not gas analysed; field based) | Participants run/walk between 2 points on a floor in sync with audio signals with incrementally increasing frequency | ++ | Need 20 m of open space | Modified protocols are available for office populations |
| Run tests (eg, 1.5 miles/2400 m; field based) | Participants run a given distance as quickly as possible | ++ | Dependent on motivation and body size | Often used in school settings |
| Step test (office or field based) | Participants step up and down on a block of a given height; each stage is associated with an increased step rate | + | Validity not well established | Portable; test can be performed in small spaces |
| Walk tests (office based; eg, 6MWT) | Participants instructed to walk as far as possible in 6 min | +/– | Poor validity in healthy populations | Useful for populations with low exercise capacity |
| Questionnaires | Questionnaire to assess fitness level | +/– | Large error in estimation of $\dot{V}O_2$ | Used mainly for population research |

CPET indicates cardiopulmonary exercise test; CRF, cardiorespiratory fitness; 6MWT, 6-minute walk test; 20mSRT, 20-m shuttle run test; and $\dot{V}O_2$, oxygen uptake.
*Tests presented were collated to give examples of various testing categories or explanations of protocols. The list presented here is not meant to be exhaustive.
†Scale ranges from +/– (least) to +++ (most) and reflects the writing groups' overall assessment of the usefulness of the test in reflecting CRF.

consumed).[22] Energy expenditure ranges from low levels used during sedentary activities (1–2 METs) to the considerable levels required during sprint interval training (9–20 METs).[22] Compared with adults, energy expended is typically higher in youth, leading to an underestimation of energy expenditure if adult reference values are used. Therefore, Table 1 includes age- and sex-appropriate MET values associated with activity of varying intensity.[20–23]

## PHYSIOLOGICAL CHANGES

Exercise-induced improvements in CRF may be explained by structural and functional adaptations leading to a better oxygen transport system[24] such as increased blood volume, myocardial contractility, ventricular compliance, and angiogenesis,[25] all of which lead to an increased cardiac output.[26,27] This was illustrated by Rowland and colleagues,[27] who found that the cardiac index (cardiac output divided by body surface area) was significantly greater in trained youth cyclists compared with their nontrained peers. On the other hand, there appears to be little difference in maximal oxygen extraction between trained and untrained youth,[28,29] and findings have been equivocal as to whether exercise-induced improvements in stroke volume result from increases in cardiac dimensions.[30]

Although the two are often conflated, physical activity and CRF are distinct but related concepts. Physical activity is voluntary movement produced by skeletal muscles that results in energy expenditure.[2] Exercise and training refer to a subset of physical activity in which the goal is to improve performance, health, or both.[2] CRF can reflect an individual's past physical activity and reflect the ability to be physically active (an individual with greater CRF has more capacity for aerobic physical activity), forming a virtuous cycle of an active-fit lifestyle. Thus, physical activity is a behavior (will do), whereas CRF represents an individual's capacity (can do) to perform certain types of aerobic physical activity.

### Key Points

1. Exercise-induced improvements in CRF are caused by structural and functional adaptations in the oxygen transport system.
2. Physical activity, exercise, and CRF are associated but distinct concepts.

## HOW TO MEASURE CRF IN YOUTH

CRF can be measured or estimated with a variety of tests and protocols. The tests used to measure CRF that require maximal effort are referred to as maximal exercise tests. Maximal exercise tests often but not always are performed in the office setting and usually measure cardiometabolic parameters such as inspiratory and expiratory gases, blood pressure, heart rate, and the electric activity of the heart. Tests that do not require maximal effort are referred to as submaximal exercise tests. Submaximal exercise tests often estimate CRF with the use of equations or nomograms that have been validated against CRF measurements obtained directly during a maximal exercise test. Submaximal tests can be used when a maximal test cannot be performed for safety, setting, or cost reasons. Although submaximal tests are easier to perform, there are often large measurement errors; thus, estimated CRF comparisons are fraught with inaccuracies. However, these tests may

**Table 3. Commonly Used Terms to Describe CRF Measures**

| Term | Unit |
|---|---|
| $\dot{V}O_2$peak (peak oxygen uptake) | L/min |
| $\dot{V}O_2$max (maximal oxygen uptake) | L/min |
| $\dot{V}O_2$peak (scaled to body weight) | mL·kg$^{-1}$·min$^{-1}$ |
| $\dot{V}O_2$max (scaled to body weight) | mL·kg$^{-1}$·min$^{-1}$ |
| No. of 20mSRT laps or stages completed | n |
| Work | W (absolute or scaled) |

CRF indicates cardiorespiratory fitness; and 20mSRT, 20-m shuttle run test.

be useful for identifying and following up those with low/unhealthy CRF. Table 2 summarizes key information on some of the commonly used tests to measure or estimate CRF.

The measurement and reporting of CRF depend on various factors: the test used and its protocol, whether CRF is measured or estimated, whether CRF measures are reported as absolute values versus indexed to body size, and participant motivation.[31] The reader is referred to CRF normative measures that are test and protocol specific.[32–34]

For each test described below, it is assumed that participants are able-bodied youth without impairment and that maximal effort is given. Although modifications can certainly be made for many of these tests for youth with physical or cognitive impairments, we do not discuss them in that context because the primary purpose of this statement is to address CRF in healthy youth.

Table 3 lists terms commonly used to describe CRF measures.

## Gas-Analyzed Tests

### *Graded CPETs*

According to the Fick principle, oxygen uptake ($\dot{V}O_2$) is the product of cardiac output (heart rate and stroke volume) and the arteriovenous oxygen difference.[35] Thus, $\dot{V}O_2$ is dependent on cardiac function, the ability of the lungs to act as gas exchange organs, the binding of oxygen to the blood that is dependent primarily on hemoglobin content, and the ability of the muscles to extract oxygen from the circulation for energy transfer. The gold standard for determining $\dot{V}O_2$ is by measuring $O_2$ and $CO_2$ partial pressures in expired air at regular intervals during graded exercise to exhaustion, typically on a treadmill or cycle ergometer. Testing CRF in this way is known by various terms such as a CPET, cardiorespiratory exercise test, or graded exercise test.

The highest oxygen uptake attained during graded exercise to volitional exhaustion ($\dot{V}O_2$max) is considered the best indicator of CRF by the World Health Organization.[36] $\dot{V}O_2$max is the reflection of the maximal oxygen flux through the lungs, transported by the circulation to the mitochondria of the exercising muscle. $\dot{V}O_2$max remains the only index that integrates pulmonary, circulatory, and muscular function into a single number. However, the utility of $\dot{V}O_2$max measurements in youth has been questioned. Traditionally, for $\dot{V}O_2$max to be determined, there must be a plateau in the oxygen uptake curve. Even the earliest pioneers appreciated that youth do not often demonstrate a plateau during incremental exercise[37] and that the greatest $\dot{V}O_2$ measured in youth, called $\dot{V}O_2$peak, is likely analogous to $\dot{V}O_2$max measured in adults.[38,39] We use both terms ($\dot{V}O_2$peak and $\dot{V}O_2$max), reflecting as closely as possible the measures used in the cited studies.

Reporting norms for $\dot{V}O_2$peak or $\dot{V}O_2$max in youth are further complicated by the wide range of body sizes even at a given age. Although CRF values often are indexed to body size, it is not clear that this is always appropriate because it may not fully account for the residual effects of body size. In a systematic review and meta-analysis, it was found that the CRF of adolescent participants with obesity was comparable to that of participants without obesity when expressed in absolute values ($\dot{V}O_2$peak in liters per minute), but lower values when scaled for weight ($\dot{V}O_2$peak in milliliters per kilogram per minute), and different still when scaled to lean mass.[40] On the other hand, if allometric scaling is undertaken, it remains sample specific and cannot necessarily be extrapolated to all populations.[41] At this time, there is no accepted standard in regard to scaling in reporting CRF; hence, attention should be paid to units when CRF is compared between participants and studies.

Although CPETs provide a wealth of data, clinicians should be aware of limitations, including the limited ability to perform this test in settings other than the office or hospital. The test requires expensive equipment and well-trained staff, which are not always available. The metabolic cart requires meticulous maintenance and calibration. Another limitation is that most CPET parameters are measured breath by breath, with a range of options to analyze the data and to filter the noise in the data. This can introduce differences between laboratories and equipment, which makes comparisons among participants and studies difficult. Finally, the pattern of activity performed during the CPET may not reflect the types of physical activities in which youth are commonly engaged.

## Non–Gas-Analyzed Tests

### *Field-Based Tests*

#### *The 20-m Shuttle Run Test*

For the reasons stated above, alternative tests for measuring CRF in youth have been developed.[42,43] One such test is the 20-m shuttle run test (20mSRT) developed by Léger et al.[44,45] The 20mSRT and its variants are now the most widely used tests to estimate CRF in youth in the world.[46]

Several different names are used for the 20mSRT: beep test, progressive aerobic cardiovascular endurance run test, and multistage fitness test. However, the protocols are very similar. Typically, youth are instructed to run at an increasing standardized pace (starting at ≈5 mph [8 km/h], increasing in 0.3-mph [0.5-km/h] increments each minute), noting the number of laps or stages during which they can keep up with the pace, which can then be compared with results from a reference population.[9]

The 20mSRT has been studied in both sexes and in a range of ethnicities and ages.[32,47] According to a systematic review, the 20mSRT is a valid estimate of CRF compared with CPET-measured CRF.[48] In this review of 73 studies addressing the criterion-related validity of field-based fitness tests in children and adolescents, there was strong evidence that the 20mSRT had moderate to high validity against CPETs to estimate CRF. Because the 20mSRT can be administered in group settings such as schools, it is efficient for testing large cohorts of youth simultaneously and thus is feasible for population-based CRF surveillance. However, as is true for all CRF tests, it is influenced by motivation and performance. If estimated $\dot{V}o_2$peak is used as an end point for comparison, large prediction errors can influence results.[49] Thus, number of laps completed or stages reached may be better end points to report. Clinicians should be aware of the specific 20mSRT protocol used when comparing with reference values.

In the United States, the 20mSRT is commonly used as a component in the FITNESSGRAM.[16] The FITNESSGRAM is a group of tests used to assess various forms of fitness in school-aged youth. In addition to the 20mSRT, the FITNESSGRAM measures body mass index (BMI), abdominal strength, trunk extensor strength, upper-body strength, and flexibility. The results are classified into various fitness zones.[16] All 50 states in the United States currently use the FITNESSGRAM to assess >22 million students each year.[34]



### *Run Tests*

In run tests, the participant is given a set distance (eg, 1.5 miles or 2400 m) or time (eg, 12 minutes) and instructed to complete the run in as short an amount of time as possible or to cover the greatest possible distance, respectively. Mayorga-Vega et al[50] recently performed a meta-analysis to determine which distance or time was most appropriate to use in youth. Of the various distances and times used, they found that the highest correlation to CPET-measured $\dot{V}o_2$max was with the 1.5-mile (2400-m) distance ($r$=0.79) and 12-minute time ($r$=0.78), showing moderate to high correlation.[50] In terms of the validity of the 1.5-mile and 12-minute run tests compared with the similarly reliable 20mSRT, data from 2 large meta-analyses[47,49] indicate that run tests are equally valid compared with the 20mSRT.

## *Office-Based Tests*

The text below describes some of the commonly used tests that are suitable for use in office settings, but this list is by no means exhaustive.

### *Ebbeling Test (Single-Stage Treadmill Walking Test)*

This test is performed on a treadmill with a 5% graded incline. Heart rate is measured after 4 minutes and is combined with speed, age, and sex to estimate CRF.[51] Nemeth et al[52] evaluated the Ebbeling test in 130 youth 11 to 14 years of age who were overweight and concluded that the CRF estimate was within 10% of the $\dot{V}o_2$max (milliliters per minute) measured by the CPET.

### *Åstrand-Rhyming Test*

This test is performed with a cycle ergometer and is often used in Europe. This test is typically performed over 6 minutes with a constant load (or single stage) aimed at producing a heart rate between 125 and 170 bpm. The heart rate and workload are used to estimate $\dot{V}o_2$max from a nomogram.[53] The Åstrand-Rhyming test has been evaluated in 11- to 12-years-olds and found to have a strong correlation of 0.82 in girls and moderate correlation of 0.52 in boys compared with CPET-measured $\dot{V}o_2$peak (liters per minute).[54] The authors did not explore the reasons for the differences in correlation coefficients between boys and girls.

### *Physical Work Capacity Corresponding to a Heart Rate of 170 bpm*

This test has been used since the 1960s. It is administered with a cycle ergometer and typically conducted with three 3-minute stages or three 4-minute stages of increasing workload. Work (Watts) is measured once the heart rate reaches 170 bpm. This capacity test was moderately well correlated with measured $\dot{V}o_2$ peak (milliliters per kilogram per minute) in 11- to 16 years-olds, with the correlation depending on the stage length (ie, 0.70 for 2 minutes, 0.56 for 3 minutes, and 0.61 for 6 minutes).[55]

### *6-Minute Walk Test*

This is the most commonly administered walk test and measures the distance walked in 6 minutes.[56] The 6-minute walk test is easy to administer, and international guidelines have been established,[57,58] along with test-specific reference standards.[59] However, the 6-minute walk test is less useful in healthy youth to estimate CRF. The 6-minute walk test shows a relatively poor correlation with $\dot{V}o_2$max, except in populations with moderate to severe limitations in CRF[58] or reduced walking capacity of <300 m.[60] Therefore, its use should be considered only when there is reason to suspect low CRF.[58,61]

*Step Tests (Queen's College or Harvard Step Tests)*

Step tests are another category of tests that use stepping up on and down from a bench in an effort to engage larger muscle mass. One of the first such protocols described in children (Harvard Step Test) involved stepping up on a 12-in bench at a rate of 24 steps per minute for a duration of 3 minutes with heart rates collected after exercise.[62] Recently, Hayes et al[63] reported the validity of a step test in elementary school children and showed that the step test, along with sex and BMI, significantly predicted $\dot{V}o_2$max ($R^2$=0.51).[63] Heart rates in youth during step tests have been strongly associated with $\dot{V}o_2$max ($r$=0.8, $P$<0.01), regardless of stepping frequency.[64] Step tests require minimal equipment, are easy to administer in limited indoor spaces, and can be administered by personnel with little or no formal training in exercise physiology, which make them a suitable alternative to CPETs to estimate CRF in office settings. The step test can also be performed on the bleachers at schools and is suitable for testing in group settings simultaneously. It is important to monitor consistency with step cadence and foot strike pattern because repeated breaches may affect results.

## Questionnaires

Some youth are unable to complete fitness testing for various reasons (body size, maturity limitations, etc), so methods to estimate CRF without objective testing have been evaluated. Questionnaires may offer the least burdensome method for examining CRF in youth. However, questionnaires are currently used for epidemiological studies, not for estimating CRF in individuals.

The International Fitness Scale (IFIS) is 1 option.[65,66] It consists of 5 questions that use a 5-point Likert scale on general physical fitness, CRF, muscular strength, speed/agility, and flexibility. The IFIS is designed to measure CRF in populations and can be completed in ≈5 minutes. Ortega et al[65] reported that in 3059 youth 12 to 18 years of age, the IFIS was linearly related to CRF (milliliters per kilogram per minute) as estimated by the 20mSRT with an odds for having a healthy CRF based on FITNESSGRAM thresholds of 7.3 (95% CI, 4.0–13.5) for those reporting very good CRF on the IFIS questionnaire. However, its usefulness at the individual level is not established.[65] It should also be noted that the correlation between the IFIS and FITNESSGRAM compares surrogates with surrogates and does not use measured $\dot{V}o_2$ as a reference.

## Key Points

1. The most accurate measure of CRF in youth is gas-analyzed (measured) $\dot{V}o_2$peak obtained during a graded CPET, but this testing cannot be universally performed.
2. Graded tests such as the 20mSRT provide the best alternative to CPET in a field setting.
3. Step tests may be a good alternative to CPET when space and resources are limited.
4. In general, tests that require more effort are preferred to tests that primarily measure function such as walk tests.
5. Estimated $\dot{V}o_2$peak can be misleading and needs to be reconciled with other factors such as the protocol and testing used and participant motivation/effort.
6. Questionnaires may provide insightful information for epidemiological purposes but are considered the least accurate method for assessing CRF.

# FACTORS AFFECTING CRF IN YOUTH

Studies have investigated the relationship between CRF and various nonmodifiable and modifiable factors, including genetics,[67] age, sex,[68] race/ethnicity,[69] physical activity and dietary patterns,[70,71] obesity,[72,73] sedentary time,[74] built environment,[75] and socioeconomics.[76,77] These topics are discussed below.

## Nonmodifiable

### *Genetics*

In adults, it has been noted that an individual's response to physical training varies widely, with some people markedly increasing their CRF (responders) and some having only a minimal increase in CRF (nonresponders).[78,79] One study suggested that nearly 50% of an individual's response to training is inherited.[67,80] Furthermore, the variance in response to aerobic training was 2.5 times higher between families than within families.[80] However, none of the nearly 300 000 single nucleotide polymorphisms studied have been found to be associated with exercise-induced changes in $\dot{V}o_2$max (milliliters per minute).[81] Thus, evidence supporting specific genetic polymorphisms influencing CRF remains weak,[82] and the mechanisms by which genes affect CRF are still unclear.[79] There is no evidence for genetic variations affecting CRF (milliliters per kilogram per minute) among elite athletes.[83] Studies in youth examining genetic differences in CRF are lacking.

### *Age and Sex*

As youth age, there is an increase in CRF as measured by $\dot{V}o_2$max (milliliters per minute) for both boys and girls.[84] Although CRF increases in both boys and girls as they age, the increase in girls occurs at a slower rate.[85,86] Regardless of age, boys have a higher $\dot{V}o_2$max than girls,[9,87] even after controlling for lean body mass and cardiac size.[87] Potential explanations for this difference include sex-related differences in muscle fiber type, oxygen extraction, or the lipid content of myofibrils.[87,88]

### *Race/Ethnicity*

In adults, $\dot{V}o_2$max has been noted to be higher in whites compared with blacks[89] and Chinese.[90] However, the relationship between race/ethnicity and CRF (milliliters per kilogram per minute) in adults weakens after adjustment for BMI, lifestyle factors, socioeconomic status, and other CVD risk factors.[91] Similarly, racial/ethnic differences in CRF in youth are unclear. Studies using data from the 1999 to 2004 and 2012 cohorts from the National Health and Nutrition Examination Survey did not find differences in CRF in youth across race/ethnicity groups ($\dot{V}o_2$max in milliliters per kilogram per minute was measured from a submaximal, gas-analyzed test).[8] However, Shaibi et al[92] found that Hispanic youth had lower $\dot{V}o_2$peak (milliliters per kilogram per minute) than non-Hispanic white and non-Hispanic black youth. This is consistent with international comparisons in which youth in South America had lower CRF compared with youth from Europe and Africa.[93] Similarly, Bansal et al[94] found that black children have lower CRF compared with white children ($\dot{V}o_2$max in milliliters per kilogram per minute). However, these differences in CRF were not adjusted for environmental and psychosocial factors or for habitual physical activity.

### *Prematurity*

Using data from Northern Ireland Young Hearts Study, investigators found that compared with those born at full term, those born even slightly early, between 37 and 38 weeks' gestation, had a 57% higher risk of having low CRF (milliliters per kilogram per minute) at 12, 15, and 22 years of age.[95] These effects were not related to decreased physical activity.[95,96] In a meta-analysis, participants born prematurely had ≈13% lower CRF than those born at term.[97] The mechanism is not clear but may be related to smaller lung volumes.

## Modifiable

### *Habitual Physical Activity and Exercise Training*

It is generally assumed that physically active youth have higher CRF. However, the strength of the association between habitual physical activity and CRF in youth is small to moderate,[98] with most of the benefits accruing only with sustained vigorous physical activity.[98–100] A number of factors may explain the lack of a strong association between physical activity and CRF in youth. First, CRF has an incompletely defined but clear hereditary component. Second, habitual physical activity levels in youth rarely achieve the vigorous intensity or duration necessary to improve CRF. Finally, challenges in the accurate assessment of both physical activity and CRF may mask the relationship.

Using an objective measure of physical activity, Gutin et al[101] found that CRF (milliliters per kilogram per minute) in youth had a stronger relationship with the time spent in vigorous physical activity than with the time spent in moderate- or light-intensity physical activities. In general, training programs of various intensities can improve $\dot{V}o_2$max or $\dot{V}o_2$peak in prepubertal youth, but engaging in increased amounts of intense physical activity can lead to up to a 10% improvement in these parameters.[102,103]

The importance of high levels of moderate to vigorous physical activity is illustrated best by studies of high-intensity interval training (HIIT). Evidence is growing that HIIT may be effective in improving youths' CRF. HIIT is typically considered to be exercise that is characterized by alternating intermittent bursts of vigorous activity with periods of rest or low-intensity activity. Studies have demonstrated that small amounts of vigorous, maximal to near-maximal activity can induce improvements in youths' $\dot{V}o_2$peak. For example, Costigan and colleagues[104] conducted a systematic review of the effects of HIIT on youth's CRF. In this review, the adjusted difference between groups in $\dot{V}o_2$max was 2.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (95% CI, 1.8–3.3; $P<0.001$) in favor of adolescents participating in HIIT. Interventions ranged from 4 weeks to 8 months in duration, and the majority of studies involved 3 sessions per week of maximal sprint running. These studies, however, provide less evidence for the exact dose (ie, frequency, intensity, time, and type) of physical activity needed to improve CRF.

Although the impact of physical activity on CRF is variable, even small improvements in CRF with increases in physical activity resulted in major health benefits in adults.[1] In fact, it is well established that moving from the lowest quintile CRF to the next-lowest quintile group is associated with the most striking health benefits in adults.[1] No studies to date have measured the impact of physical activity in youth with low baseline CRF, but this is a critical health question to answer because they potentially stand to benefit most from intervention.

### *Sedentary Time*

The time spent sedentary makes up as much as 75% of a 15-year-old's waking hours and increased from 7 to 8.2 h/d from 2003 to 2016 in adolescents in England and the United States.[105,106] A recent American Heart Association statement on sedentary time in adults[107] noted several meta-analyses suggesting a strong relationship between sedentary time and all-cause death. In a recent meta-analysis in adults, the negative effects of high levels of sedentary time were reduced with, but not eliminated by, high levels of moderate to vigorous physical activity.[108]

The relationship between sedentary time and CRF in youth is unclear. Studies have demonstrated both the presence[74,109,110] and absence[111,112] of a relationship. In a large study of 11- to 13-year-old girls, objectively measured physical activity improved CRF (milliliter per fat-free mass per minute), but there was no relationship between CRF and objectively measured sedentary time.[113] In another study, CRF was associated with objectively measured sedentary time independently of time spent in moderate to vigorous physical activity.[74] The authors of a recent meta-analysis examining the cross-sectional association between total sedentary time and CRF in children and adolescents (n=4499 participants) found conflicting results. There was a significant association in children ($r$=–0.06, $P$=0.037), whereas no association was found in adolescents ($r$=0.02, $P$=0.7).[114]

### Obesity

Youth with obesity who are less physically active exhibit lower $\dot{V}o_2$max (milliliters per kilogram per minute) than their normal-weight peers.[115] Byrd-Williams et al,[116] in a longitudinal study evaluating risk factors for the development of type 2 diabetes mellitus among Hispanic youth, found that high CRF (milliliters per minute) is associated with less subsequent weight gain over time in boys but not in girls. Specifically, this study found that for each 15% increase in $\dot{V}o_2$max from baseline, there was an associated 1.4-kg lower fat mass over 4 years. Therefore, optimal CRF could modify BMI, suggesting a bidirectional relationship between obesity and CRF. Reports have evaluated the relationship between genes associated with obesity and $\dot{V}o_2$max/trainability. Such studies have suggested that there is a shared genetic thread between obesity and CRF regardless of whether $\dot{V}o_2$max is indexed to fat-free mass or total body weight.[117] Lifestyle interventions, regardless of whether youth gain or lose weight, may have a beneficial effect on CRF. In a study of 11- to 18-year-old girls enrolled in a 6-month program of dietary counseling combined with supervised aerobic and resistance exercise training, CRF improved in those who lost weight more than in those who did not, but $\dot{V}o_2$max improved with intervention in both groups as a function of the increase in fat-free mass.[118] However, the authors do not report the potential interplay between the dietary and exercise training aspects of this lifestyle intervention.

### Diet

An overall healthy dietary quality score was associated with better CRF in the Coronary Artery Risk Development in Young Adults study in all race-sex groups of youth studied except blacks.[71] A dietary pattern specifically rich in fruits and vegetables was associated with healthy CRF in New Zealand and European youth.[119,120] The nutritional contributions to CRF are rooted in mitochondrial energetics, which are fundamental to skeletal muscle oxidative capacity and efficiency and therefore to CRF.[121]

As defined at the beginning of this statement, CRF reflects the integrated ability to transport oxygen from the atmosphere to the mitochondria to perform physical work. A signature feature of mitochondria is their ability to proliferate or, conversely, to be degraded in response to nutritional and extracellular environmental stimuli. Exercise training and dietary patterns rich in omega 3 fatty acids and polyphenols are the principal external influences known to promote mitochondrial bioenergetic pathways.[122] Several specific essential fatty acids and polyphenolics, including those from cocoa, apples, beets, pomegranates, grapes, olives, and cruciferous vegetables, have been shown to increase mitochondrial biogenesis and to improve mitochondrial function.[123] Nitrate, an inorganic ion abundant in fruits and vegetables, can also be converted in the mammalian mouth and gut to bioactive nitric oxide, further reducing the oxygen cost of exercise.[124]

### Social, Economic, and Environmental Factors

Disparities in CRF may be socioeconomically driven, with rates of both poor nutrition and physical inactivity greatest among urban youth.[125] In addition, the effects of the environment on lifestyle and CRF may be mediated through various levels of physical activity resulting from the built environment. Gahche et al[8] did not find a difference in socioeconomic status and CRF (submaximal, gas-analyzed CRF measured in milliliters per kilogram per minute), but other studies have found that poor socioeconomic status is associated with low CRF (measured with the 20mSRT) in youth.[77]

A recent study identified a strong negative association between country-level CRF and income inequality. In countries with a wide income gap between rich and poor residents, youth had poorer CRF.[93] In a review, the same authors reported that countries with a widening economic gap between rich and poor residents had less favorable CRF trends (ie, large declines).[9] Although these assessments of income inequality may not be stringent, these data provide some proof of concept that there are social and economic determinants of CRF.[126]

Figure 1 summarizes key influencers of CRF and outcomes influenced by CRF.

## Key Points

1. Hereditary factors are known to influence CRF, but specific genes that explain these differences have not yet been elucidated.

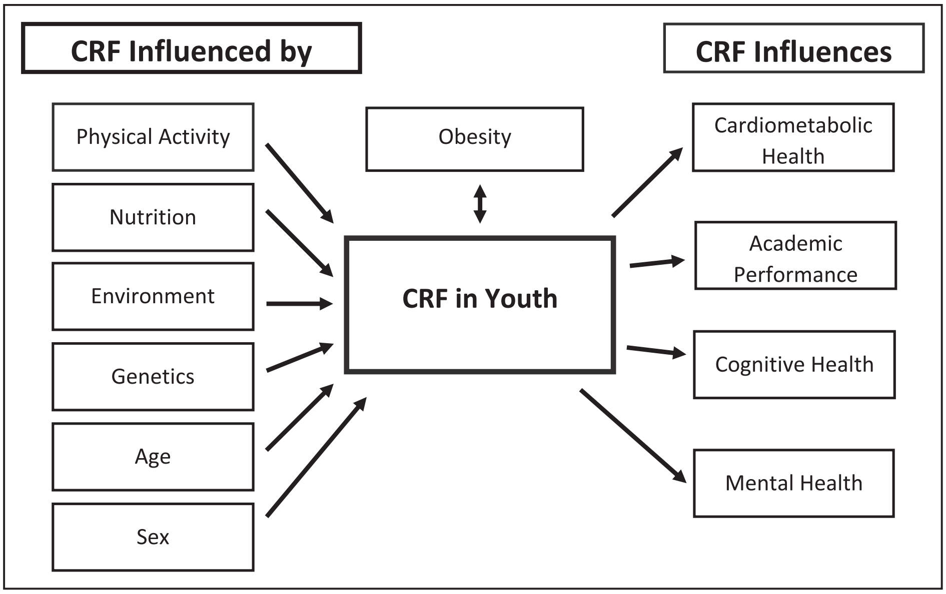


**Figure 1. Cardiorespiratory fitness (CRF) in youth: key influencers and effects.**
Relationship between CRF in youth and variables.

2. Racial/ethnic differences in CRF seem to be related to extrinsic factors such as lifestyle, other CVD risk factors, and socioeconomic status.
3. Age, sex, and vigorous physical activity are the most influential determinants of CRF in youth. The influence of modifiable factors on CRF is likely mediated by duration, frequency, and intensity of physical activity.
4. There is little evidence to suggest that sedentary behavior is related to CRF in youth once adjusted for objectively measured physical activity.
5. Nutrient modulation of CRF may be mediated by mitochondria number and function.

# IMPLICATIONS OF CRF FOR HEALTH OUTCOMES

## CRF and Health Outcomes in Adults

Numerous large studies have established that in adults low CRF is associated with greater risk for all-cause mortality, CVD events, and cancer mortality independently from, and perhaps more strongly than, traditional risk factors.[1,127,128] A nonlinear pattern whereby the largest benefit occurs between the least fit and next-least fit groups underscores the potential benefits of even modestly increasing CRF in the most sedentary individuals,[1] but there are no studies in youth in this regard. Apart from mortality, low CRF in adults is also associated with greater risks for congestive heart failure, stroke, type 2 diabetes mellitus, some cancers, and neuropsychological disturbances (eg, dementia, anxiety, and depression).[1,127,129] Most important, improvements in CRF over time are associated with reduced mortality and morbidity.[129,130]

## CRF Tracking

In light of these well-documented benefits of optimal CRF in adults, the degree of CRF tracking from childhood to adulthood is of interest. Several studies have found that the degree to which CRF tracks into adulthood varies by methodology (eg, measured or estimated $\dot{V}O_2$), sex, and length of follow-up. In general, studies found that tracking was low to moderate for spans up to 40 years.[131–134]

## Childhood CRF and Health Outcomes

Longitudinal data on the relationship between CRF in youth and CVD end points have come primarily from studies following up male military recruits. These studies have collectively demonstrated inverse associations between CRF (Watts per kilogram) in youth and all-cause mortality (hazard ratio [HR], 0.49 [95% CI, 0.47–0.51] for highest versus lowest quintile of CRF),[135] CRF and myocardial infarction (HR, 0.82 [95% CI, 0.80–0.85] per 1-SD higher CRF),[5] CRF (Watts) and stroke (HR, 0.84 [95% CI, 0.81–0.88] per 1-SD higher CRF),[136] CRF (Watts per kilogram) and heart failure (HR, 1.60 [95% CI, 1.44–1.77] for low versus high CRF),[137] and CRF (Watts) and disability (HR, 1.85 [95% CI, 1.71–2.00] for low versus high CRF).[138]

Childhood CRF has also been associated with cardiometabolic risks and a variety of more proximal health outcomes.[139] In a study of 154 youth followed up for 24 years, improvement in CRF was associated with lower arterial stiffness (for each unit increase in measured CRF adjusted for body weight, carotid compliance was higher [*P*=0.04], even after adjustment for several risk factors).[140] Cross-sectional and short-term longitudinal studies have also shown an inverse relationship of childhood CRF with adiposity,[116,141,142] waist circumference,[143] blood pressure,[144] insulin resistance, nonalcoholic fatty liver disease,[145,146] and a clustered cardiometabolic risk score.[139] Furthermore, in a systematic review and meta-analysis, low CRF was significantly associated with the development of pediatric metabolic syndrome.[147] In the only prospective study included in this meta-analysis, youth with metabolic syndrome had an odds ratio of 6.1 (95% CI, 1.2–60.3) for having had low CRF (milliliters per kilogram per minute) 7 years earlier.[148]

Given these associations, several studies have developed criterion-referenced CRF cut points to help identify youth with high cardiometabolic risk.[149] These studies attempt to define CRF thresholds in youth to help providers identify those with the highest risk of cardiometabolic disease. In a meta-analysis combining 7 published criterion-referenced standards on 9280 youth 8 to 19 years of age from 14 countries, CRF <35 $mL·kg^{-1}·min^{-1}$ for girls and 42 $mL·kg^{-1}·min^{-1}$ for boys identified youth with a higher likelihood of adverse cardiometabolic risk factors (eg, insulin resistance, dyslipidemia, adiposity, high blood pressure) with odds ratios of 5.7 (95% CI, 4.8–6.7) for girls and 3.6 (3.0–4.3) for boys.[150] For ease of interpretation, 20mSRT stages that achieve these CRF cut points for boys and girls of different ages also have been published.[150]

## CRF and Lung Function

In a population-based study with cross-sectional and longitudinal components, each 1-SD higher CRF was associated with 2% to 3% greater predicted value of both forced expiratory volume in the first second and forced vital capacity among individuals 9 through 38 years of age. Moreover, improvements in CRF during youth were associated with better lung volumes.[151] However, these improvements were not necessarily related to any measures of change in physical activity or interventions undertaken during the course of the longitudinal follow up.

## Childhood CRF: Cognitive and Mental Health Outcomes

CRF has been associated with a range of cognitive and academic outcomes in youth. Academic achievement generally has been found to be positively associated with CRF, although most studies have used a cross-sectional design.[3,6,152] Among longitudinal studies, maintaining a healthy CRF or improving CRF over time has been associated with better academic achievement.[152–154] For example, in a recent large longitudinal study of ≈400 000 Taiwanese junior high school students followed up for 3 years, there was a dose-dependent, positive association between number of years with high CRF (top age- and sex-specific quartile versus bottom 3 quartiles of CRF for all 3 years) and standardized test scores in the third year, with between-group differences up to 0.3 SD for math and science after adjustment for sex, BMI, and urbanization.[155] Although effect sizes have varied across studies, even small effect sizes could be impactful at the population level.

High CRF may improve school achievement through improving cognitive abilities or psychological factors.[6] Higher CRF has been associated with better attention allocation and cognition modulation (as assessed by task performance and event-related brain potentials) and more efficient neural activation in the prefrontal and parietal cortices (as assessed by functional magnetic resonance imaging).[156] In a randomized trial involving a physical activity intervention in 8-year-olds, neural efficiency increased in direct proportion to the increase in CRF.[157] In another intervention, youth receiving structured physical activity had an increase both in performance on cognitive tests and in $\dot{V}o_2$max (milliliters per kilogram per minute), although the relationship between the change in $\dot{V}o_2$max and cognitive performance was not assessed.[158] Higher CRF has also been associated with better relational memory (learning about the relationship between 2 stimuli), potentially mediated by larger bilateral hippocampal volume.[156] Indeed, a variety of structural brain changes (eg, altered cortical gray matter thickness and integrity of white matter tracts) have been observed in association with CRF, potentially related to the effects of CRF on angiogenesis, neurogenesis, and neuroplasticity via increases in brain-derived neurotrophic factor.[6,7,152]

Furthermore, better childhood CRF has been associated with a lower incidence of mental disorders (mood disorders, psychosis, or suicidality)[159] and improved self-worth[160,161] and life satisfaction.[162,163] In fact, in an exercise intervention study in children, effects on mental health outcomes were more strongly related to improvements in CRF than to changes in body composition.[161] These mental health effects are thought to be related to structural brain changes and changes in brain signaling (eg, serotonin).

## Key Points

1. A linear inverse relationship exists between CRF during the youth years and all-cause mortality, as well as CVD across the life span.

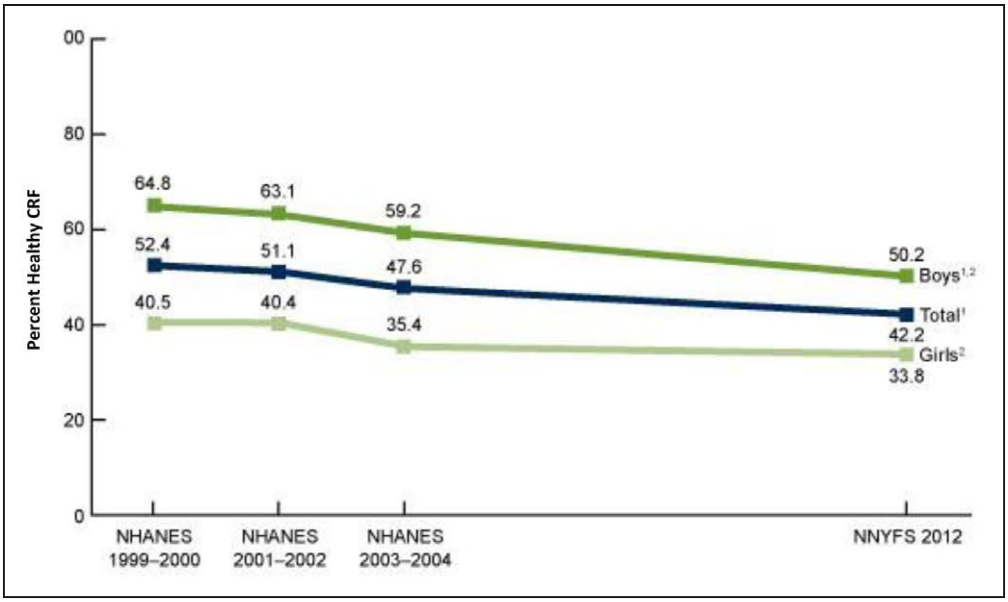


**Figure 2. Percentage of youth 12 to 15 years of age who had healthy cardiorespiratory fitness by sex and survey period: United States, 1999 to 2004 and 2012.**[8]
NHANES indicates National Health and Nutrition Examination Survey; and NNYFS, NHANES National Youth Fitness Survey.

2. In youth, a protective inverse association has been demonstrated between CRF and multiple conditions that compound cardiovascular risk, including but not limited to metabolic syndrome, type 2 diabetes mellitus, nonalcoholic fatty liver disease, and mental health disorders.
3. CRF is also positively associated with cognitive function, self-worth, and life satisfaction in youth.

## EPIDEMIOLOGY OF CRF IN YOUTH: TEMPORAL TRENDS

Both in the United States and internationally, CRF in youth is thought to have declined over the past 40 years.[8–10] Globally, a decline in CRF in youth has been noted since the 1960s.[11] Armstrong et al[103] reported a small but downward trend in the gas-analyzed $\dot{V}O_2$peak (milliliters per kilogram per minute) in ≈4000 youth from 5 countries between 1962 and 1994. Although this represents the best available information on trends in gas-analyzed $\dot{V}O_2$peak, the study is dated. No study has examined trends in allometrically scaled $\dot{V}O_2$peak for youth.

### United States

In a nationally representative sample in the United States, only 42% of 12- to 15-year olds had healthy CRF (milliliters per kilogram per minute) in 2012 (Figure 2).[8] The percentage of boys who had healthy CRF decreased significantly from 65% in 1999 to 2000 to 50% in 2012. For girls, the percentage decreased over the same time period, although not as substantially, from 41% to 34%.[8] In addition, 54% of normal-weight youth had healthy CRF, whereas only 30% of youth who were overweight (BMI ≥85th percentile for age and sex) and 20% of youth with obesity (BMI ≥95th percentile for age and sex) had healthy CRF. This percentage did not differ by race and Hispanic origin or ratio of family income to poverty.[8] Others have reported declines in mean CRF of 0.9 $mL·kg^{-1}·min^{-1}$ per decade between 1995 and 2013 in 166 900 US youth 9 to 17 years of age.[9]

### Internationally

CRF declined by >7% from 1981 to 2014 in a recent analysis of 137 studies that reported 20mSRT data on youth 9 to 17 years of age.[9] Temporal trends were estimated at the country-sex-age level for 19 high-income and upper-middle-income countries. CRF (milliliters per kilogram per minute) trends varied over time and across countries. Moderate CRF declines were seen in earlier years; these declines then slowed and have been stable since 2000.[9] However, not all data suggest that there has been a decrease. In Greece, with the use of a measure of CRF based on the 20mSRT, there was an increase in CRF in both sexes from the cohorts evaluated in 1992 to 1993 and 2006 to 2007.[164] It should be noted that these CRF estimates based on the 20mSRT, which are only moderately correlated with $\dot{V}O_2$peak, remain imperfect.

A significant percent of the reported decline in CRF (milliliters per kilogram per minute) may be attributable to the increasing prevalence of obesity.[9] Caution should be used in the interpretation of associations between $\dot{V}O_2$peak when indexed to body weight because indexed values may systematically underestimate $\dot{V}O_2$peak in youth with obesity. Thus, a weight-scaled

CRF may underestimate fitness in this population. For example, in a study of Norwegian military volunteers over a 22-year period, CRF declined by 8% but body weight increased by 7%, suggesting only a minimal change in absolute $\dot{V}O_2$max (milliliters per minute) over this period.[165] Similarly, Andersen and colleagues[166] found that there was no difference in absolute $\dot{V}O_2$max (milliliters per minute) between cohorts tested in 1983, 1997, and 2003 in both boys and girls. The authors noted that there were changes in BMI and that maximal performance decreased with time, suggesting that these trends need to be validated in rigorous studies before determining whether there have been secular decreases in CRF over the past several decades.[166] Although it is difficult to know whether declines in field-tested CRF reflect a true decline in underlying cardiovascular function, an increase in body size, or both, tests such as the 20mSRT, 1.5-mile run, and 12-minute run suggest a decline in underlying $\dot{V}O_2$peak (milliliters per kilogram per minute). Trends in these weight-bearing CRF tests better reflect trends in typical youth aerobic activities of daily living.

### Key Points

1. One-half of boys and two-thirds of girls 12 to 15 years of age do not have healthy CRF.
2. Only 1 in 5 youth with obesity has healthy CRF.

## GAPS AND LIMITATIONS

1. Although several tests beyond CPETs are currently available to measure CRF in office and field settings in youth, there is a pressing need for standardization of testing protocols, uniform interpretation of tests, and data harmonization. Tests such as the step test may be a suitable alternative to CPETs in the office setting but need further study.
2. Stronger clinic-community partnerships to share results or to easily access CRF assessments performed at different settings would be meaningful in providing a customized counseling and intervention.
3. Research is needed to further determine which interventions improve CRF in youth, including youth with obesity or low CRF. We need more research to determine thresholds at which intervention is needed.
4. There is a need for continued collection of data to assess the impact of CRF in youth on CVD outcomes because currently longitudinal data are limited.
5. Furthermore, research should aim to determine the reasons for the reported decline in CRF in youth in order to develop strategies to reverse this trend.

## CONCLUSIONS

Healthy CRF is positively associated with cardiovascular health, academic achievement, and mental well-being in youth. Accurately and reliably measured CRF may identify youth who would benefit from lifestyle interventions but may be missed by subjective physical activity recall, anthropometric measures, or CVD risk factor testing, which are current standards of care.

Although accurate assessment of CRF in youth has traditionally relied on CPETs, less resource-intensive tests, in particular the 20mSRT in the field setting, are useful. Office-based CRF testing that can be performed by providers with little or no formal training in exercise physiology and low-cost equipment is also superior to physical activity recall. With future research, a practical, widely applicable test to estimate CRF in office settings may become a reality and an essential part of health assessment in all youth during office visits.

Every child will benefit from a CRF estimate as part of a yearly physical. Repeated bursts of vigorous physical activity, including HIIT, improve youth CRF. Public health measures and school policies that support lifestyle improvements to improve CRF in individuals and populations are expected to result in substantial health and cognitive benefits.

## ARTICLE INFORMATION

The findings and conclusions in this report are those of the authors and do not necessarily represent the official positions of the American Heart Association or the Centers for Disease Control and Prevention.

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

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*Modest.

†Significant.

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