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Normative Values for Cardiorespiratory Fitness Testing Among US Children Aged 6–11 years

Jaime J. Gahche,
Brian K. Kit,
Janet E. Fulton,
Dianna D. Carroll
Centers for Disease Control and Prevention

Thomas Rowland
Baystate Medical Center

Abstract

Background: Nationally representative normative values for cardiorespiratory fitness (CRF) have not been described for US children since the mid 1980s.

Objective: To provide sex- and age-specific normative values for CRF of US children aged 6–11 years.

Methods: Data from 624 children aged 6–11 years who participated in the CRF testing as part of the 2012 National Health and Nutrition Examination Survey National Youth Fitness Survey, a cross-sectional survey, were analyzed. Participants were assigned to one of three age-specific protocols and asked to exercise to volitional fatigue. The difficulty of the protocols increased with successive age groups. CRF was assessed as maximal endurance time (min:sec). Data analysis was conducted in 2016.

Results: For 6–7, 8–9, 10–11 year olds, corresponding with the age-specific protocols, mean endurance time was 12:10 min:sec (95% CI: 11:49–12:31), 11:16 min:sec (95% CI: 11:00–11:31), and 10:01 min:sec (95% CI: 9:37–10:25), respectively. Youth in the lowest 20th percentile for endurance time were more likely to be obese, to report less favorable health, and to report greater than two hours of screen time per day.

Conclusions: These data may serve as baseline estimates to monitor trends over time in CRF among US children aged 6–11 years.

Keywords

cardiorespiratory endurance; youth; physical activity; NHANES; NNYFS

Address author correspondence to Jaime J. Gahche at dvt4@cdc.gov.
Gahche and Kit are with the National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, MD. Fulton is with the Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Atlanta, GA. Carroll is with the Centers for Disease Control and Prevention, National Center on Birth Defects and Developmental Disabilities Atlanta, GA. Rowland is with the Dept. of Pediatrics, Baystate Medical Center, Springfield, MA.

Cardiorespiratory fitness (CRF) is critical to the optimal functioning of the body's cardiorespiratory system and is associated with better health outcomes and lower mortality in adults (5,12,14,19,25,37,38,43,51,52). While children and adolescents are not likely to develop cardiovascular disease (CVD), a growing body of evidence indicates that youth with lower levels of CRF have an increased risk of developing CVD risk factors, including hyperlipidemia, high blood pressure, insulin resistance and obesity, early in life (3,8,11,15,16,20,24,26–29,39,40,44,45).

School-based fitness assessments have been conducted for decades, although the most recent nationally representative assessment of the fitness of U.S. children as young as 6 years was conducted in the mid 1980s. The National Children and Youth Fitness Studies I and II assessed a nationally representative sample of students aged 6–18 years. In these studies, CRF was assessed by a walk/run test and normative values of endurance times were reported (7,41). There have been more recent studies of CRF in youth on the national level, however these studies focused on youth 12+ years (17,36). Accordingly, the National Health and Nutrition Examination Survey (NHANES) National Youth Fitness Survey (NNYFS) was conducted in 2012, as part of the Department of Health and Human Services' priority to "advance activities to improve nutrition and increase physical activity to promote healthy lifestyles and reduce obesity-related conditions and costs. (46)." NNYFS was designed to provide baseline normative values for health-related fitness assessments for children aged 3–15 years in the US. One of these assessments was a measure of CRF, specifically a measure of endurance performance, using maximal treadmill exercise test protocols for children aged 6–11 years. These data provide the most recent nationally representative CRF data for U.S. children aged 6–11 years. CRF for adolescents aged 12–15 years was measured in NNYFS using age-appropriate protocols developed for the 1999–2004 NHANES to allow for examination of secular trends in CRF among adolescents.

The first aim of this study is to describe the age- and sex-specific nationally representative normative endurance times, using standardized exercise testing protocols, among US children ages 6–11 years. The second aim is to assess endurance by socioeconomic and selected behavioral characteristics.

Materials and Methods

Sample

The NHANES is conducted by the Centers for Disease Control and Prevention's National Center for Health Statistics. The NNYFS was a one-year survey conducted in 2012 alongside the 2011–2012 NHANES survey, to obtain nationally representative data on the physical activity and fitness levels of children and adolescents aged 3–15 years. Both of these population-based surveys use a complex, stratified, multistage probability cluster sampling design (6,21). The NNYFS conducted a home interview followed by physical assessments in a mobile examination center, including cardiorespiratory fitness assessments and body measurements. For 6- to 11-year-olds, the age group included in this analysis, the examination response rate was 75.0% (732 of 976) (31).

The survey protocol was approved by the Research Ethics Review Board at the NCHS and written informed consent was obtained from each participant's parent or guardian. Participants aged 7–11 years provided additional signed assent to participate.

Cardiorespiratory Fitness Testing

CRF was measured as endurance time (in seconds) using a maximal treadmill exercise test (Cardiac Science Quinton TM55 treadmill). Trained examiners conducted the CRF tests using a standardized protocol, which included scripts, procedures for conducting the test, and exercise test protocols (30). Participants were assigned to one of three age-specific treadmill testing protocols varying in grade and speed (Table 1). The objective of the treadmill test protocols was to maximally exercise participants for 5–12 min. The protocols include: a 1-min warm-up, seven 2-min stages designed to maximally exercise most children, three 1-min additional stages for exceptionally fit children, and a 2-min recovery stage. The protocols were developed by an expert in the field of pediatric exercise testing and were tested in a feasibility study before implementation, as described elsewhere (6).

Two examiners were present during the treadmill test at all times: one monitoring the participant's heart rate and operating the treadmill and the other standing on the side of the treadmill to encourage and monitor the participant. Examiners encouraged the children to perform to volitional fatigue. The test was stopped after the child indicated they could no longer continue despite strong verbal encouragement. The participant immediately moved into the recovery stage where they continued walking at a slope of 0% and a speed of 2 mph for 2 min.

Heart rate was monitored throughout the exercise tests using four leads with electrodes attached to the participant's chest (Cardiac Science Quinton Q-stress System). A maximal heart rate (MHR) of ^{3}185 beats per minute (bpm) at the end of the test was used to indicate maximal performance for this analysis (49). The average room temperature was 70.4 °F (20.3 °C) and the average relative humidity was 49.7%. Additional details of the maximal exercise test are available in the NNYFS Treadmill Examination Manual (30).

Analytic Sample

Data analysis was conducted in 2016. Among the 732 participants eligible for the treadmill test, 16 were excluded because of medical history, safety concerns, and physical limitations. An additional 19 participants did not receive the exam due to participant refusal, no time and equipment issues. The exam was terminated early for 15 participants due to problems adhering to the protocol, safety issues and other issues. Of the 682 that completed the test, 58 were excluded for not meeting the maximal performance requirement of a MHR of ^{3}185 bpm. The final analytic sample size was 624. After the exclusions, there were no significant differences in the weighted distribution of characteristics between the analytic sample and the overall sample that was examined in the mobile examination center (Table 2).

Covariates

Age was categorized into three groups: 6–7, 8–9, and 10–11 years of age corresponding to the three treadmill exercise test protocols. Proxy-reported race and Hispanic origin were grouped as non-Hispanic white, non-Hispanic black, Hispanic, and “other.” The “other” racial or ethnic group was included in the estimates for the total sample, but was not presented separately as a group.

Two measures of socioeconomic status were included in the analysis: family income to poverty level ratio (FIPR) and the highest level of education attained by the head of household (less than high school, completed high school or general equivalency diploma (GED), and more than high school). The FIPR is calculated by dividing family income by a poverty measure specific for family size (47) and larger FIPRs indicate greater income. Income for this analysis was categorized as FIPR < 1.85 (which establishes income eligibility for certain federal programs, including reduced school lunch), 1.85–3.49, and ≥ 3.5.

Proxy-reported physical activity was obtained from the physical activity questionnaire using the question: “During the past 7 days, on how many days was [child’s name] physically active for a total of at least 60 minutes per day? Add up all the time [child’s name] spent in any kind of physical activity that increased [his/her] heart rate and made [him/her] breathe hard some of the time.” Responses ranged from 0 to 7 days. Days of physical activity in the past 7 days was classified in this analysis as 0–4 days per week, 5–6 days per week and 7 days per week.

Screen time, defined as hours of TV watching plus computer use, was estimated from responses to 2 separate questions: 1) “Over the past 30 days, on average how many hours per day did [child’s name] sit and watch TV or videos?”, 2) “Over the past 30 days, on average about how many hours per day did [child’s name] use a computer or play computer games outside of school?”. For both questions, response options were as follows: none, less than 1 hr, 1 hr, 2 hr, 3 hr, 4 hr, and 5 or more hours. Screen time was calculated by adding the time contributed from both questions. Children were categorized as meeting screen-time recommendations if the combined screen time was 2 hr or less per day (2,32). The response of “< 1 hour” was assigned the value of 0.5 hr (18).

Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. BMI categories were defined as underweight/normal weight (BMI < 85th percentile), overweight (BMI 85th-<95th percentile), and obese (BMI ^{3}95th percentile) based on the 2000 CDC Growth Charts (33). Proxy-reported health status was characterized as excellent, very good, and good/fair/poor, using the question: “I have some general questions about [child’s name] health. Would you say [child’s name] health in general is excellent, very good, good, fair, or poor?” Current asthma was defined as having a “yes” response to two questions: 1) “Has a doctor or other health professional ever told [child’s name] that [child’s name] has asthma?” and 2) “Does [child’s name] still have asthma?”

Statistical Methods

Statistical analyses were conducted using SAS version 9.3 (SAS Institute Inc.) and SAS-callable SUDAAN version 11.0 (Research Triangle Institute). SUDAAN was used to account for the complex sample design. Standard errors were calculated by Taylor series linearization. The mean and selected percentiles (20th, 40th, 50th, 60th, and 80th) of maximal endurance times are reported. These percentiles were chosen because there were not adequate sample sizes to support reporting percentiles <20th or >80th percentile (22) and because a report from the Institute of Medicine (35) recommended interim cut-points be derived for the lowest performers based on the cardiorespiratory endurance distribution curve and suggested the 20th percentile to identify youth with low fitness. Prevalence of maximal endurance time <20th percentile for age- and sex-specific cut-points is considered the lowest performers and will be referred to as lowest fitness group. Confidence limits of 95% were constructed using the Wald method.

Statistical testing of differences between groups in mean endurance time and prevalence of low fitness between groups were assessed using a univariate *t* statistic at the $p < .05$ significance level with the appropriate degrees of freedom. To test for linear trends, the null hypothesis of a nonlinear trend was examined using orthogonal polynomials. All analyses used the examination sample weights, which account for unequal probabilities of selection, person-level nonresponse, and a post stratification adjustment to the estimated U.S. population.

To examine if using different heart rate criteria affected study conclusions, we conducted a sensitivity analyses to examine the mean and distribution of endurance times by age and sex using age-specific heart rate equations rather than a maximal heart rate of ≥ 185 bpm (23).

Results

Weighted characteristics of the analytic sample are presented in Table 2. In 2012, 52.5% of US children aged 6–11 years were girls and 54.1% were non-Hispanic white. About 66% were normal or underweight and 11.8% currently had asthma.

The age- and sex-specific estimates for mean, median and percentiles for endurance times are presented in Table 3. The average endurance time (min:sec) was 12:10 for children aged 6–7 years, 11:16 for children aged 8–9 years and 10:01 for children 10–11 years. Boys in general had slightly higher endurance times for each age group compared with girls, although this was only statistically significant in the oldest age group (10:28 versus 9:38).

Prevalence of those in the lowest fitness group, defined as endurance time less than the 20th percentile, differed by some health and behavioral characteristics (Figure 1). Obese children and overweight children (56.3% and 20.7%) had higher prevalence of being in the in the lowest fitness group compared with children that were normal or underweight (9.8%). Among children who reported PA in all of the past 7 days, 15.2% had low endurance time while 26.4% who reported 0–4 days of PA in the past 7 days had low endurance time. Furthermore, 12.6% and 24.2% of children who met screen time recommendations of ≤ 2 hr and who had > 2 hr of screen time were categorized in the lowest fitness group ($p < .05$). A higher percentage of those in the lowest fitness group had very good and good, fair or poor health status (20.1% and 29.1%) compared with excellent health status (15.2%).

A sensitivity analysis examined the mean and distribution of endurance times by sex and age using age-specific heart rate equations (23) rather than a MHR of ≥ 185 bpm. In this analysis, there were no significant differences found between estimates.

The age-specific protocols elicited similar maximal mean heart rates for the three age groups [(ages 6–7, 203 (*SE* 0.4); ages 8–9, 203 (*SE* 0.7); ages 10–11, 203 (*SE* 0.3)] (data not shown).

Discussion

This study provides the first nationally representative data on cardiorespiratory fitness (CRF) for children aged 6–11 years, using age-specific maximal treadmill exercise protocols, since the mid-1980s (41). It is also the first nationally representative study using age-specific maximal treadmill exercise protocols on children aged 6–11 years. In a nationally representative sample of US children, aged 6–11 years, age-specific exercise test protocols were successfully implemented and a MHR ^{3}185 was achieved in 91.5% (624/682) children who were eligible and completed the test. The normative reference values we report are important in establishing a baseline to compare with future studies that may incorporate these same protocols.

While there were no difference in CRF among boys and girls aged 6–9 years, boys aged 10–11 years had a higher endurance time compared with girls in the same age group. In another analysis of NNYFS data assessing muscle strength, a similar pattern was observed, with larger differences found between girls and boys in older age groups (13). Consistent with previous research, we observed that higher weight status (1,9,48,50) and higher screen time (42) were associated with less favorable endurance. It should be noted that comparing and contrasting our study findings to other studies is limited because different studies have employed different protocols and most studies of endurance time in young children are not nationally representative.

Using a treadmill can improve standardization and is feasible when space is limited. Moreover, since the NNYFS was population-based and conducted in children as young as 6 years, the age-specific protocols were developed and tested to take into account age, fitness levels, coordination, and motivation of the participant. Although the age group was relatively narrow, children ages 6–11 years have different levels of coordination, development and familiarity with treadmills. Ultimately, for our study we used an age-specific standardized protocol because it allows for the testing of all children including very young age groups, and not just exceptionally fit children or those that are more familiar with a treadmill.

The NNYFS CRF protocols met many of the recommendations set forth for exercise testing in children. These criteria include a test that is of progressively increasing exercise intensity (graded exercise test), last until the subject cannot maintain the required workload (fatigue), uses large muscles, ideally lasts 8–12 min and has shorter stages to keep children engaged and motivated (34). The NNYFS protocols were successful even in the youngest group, where the majority of children were able to provide a maximal test as indicated by a maximal mean heart rate of over 200 bpm in all age groups. Endurance times met recommendations (34) of being within 8–12 min, with the mean for boys 11:27 min:sec and for girls 10:52 min:sec.

Limitations

Several Limitations of Our Study are Noted.—First, heart rate, but not other physiological measurements including peak oxygen uptake, was collected to determine if a maximal effort was achieved. However, the achievement of maximal heart rate is one of the most reliable criteria in children (4). In addition, the NNYFS protocols were conducted by three exceptionally motivated and trained examiners ensuring volitional fatigue. While this is a strength for our study, this may be difficult to achieve in all settings and for other studies. Some variables were not able to be controlled during the CRF testing such as time of last meal, exercise outside of the examination, sleep patterns before testing, and caffeine consumption. Physical activity and TV and computer use were proxy-reported which is subject to measurement error for a variety of reasons, including social desirability to report more favorably (10). Proxy-report also may be difficult to accurately report and depends heavily on the time spent with the child. There were 624 children who participated in the CRF assessment which is a larger sample size than other studies but not large enough to conduct stratified analyses across multiple domains and we cannot comment on the feasibility of a much larger scale endeavor. Another limitation is that reliability and validity were not tested for these protocols. Lastly, our assessment of low fitness is based on the 20th percentile derived from our sample and thus represents a statistical definition and not criterion-referenced.

Our Study has Several Strengths

The tests were conducted on a nationally representative sample of the US population aged 6–11 years that included all levels of fitness, BMI, and race and Hispanic origin. The CRF measurements were collected with standardized protocols. These protocols can be used in other studies that are conducted on children and can be repeated in large population-based studies to monitor CRF levels over time.

Physical fitness is an important marker of current and future health for children. This study provides the sex- and age-specific normative values for maximal endurance time for US children aged 6–11 years old. This marks the first time a maximal exercise test has been conducted on children aged 6–11 years in a nationally representative sample. These protocols and sex- and age-specific reference values can be used to estimate CRF levels of children in other studies and can also be used as baseline values to monitor trends in CRF over time.

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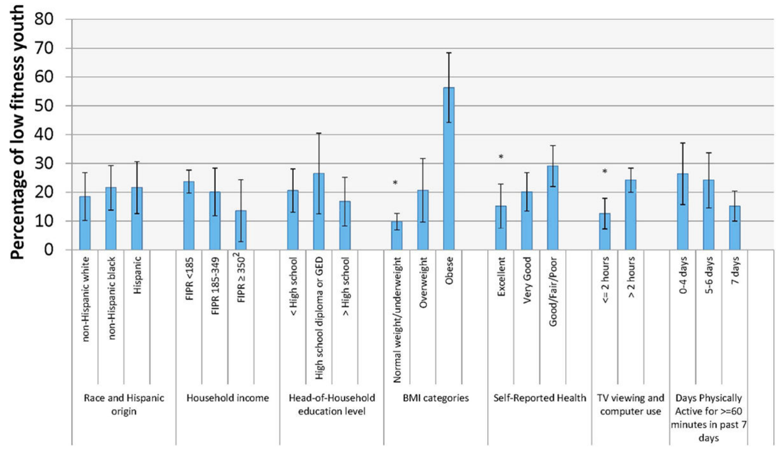

Figure 1 —.

Prevalence of youth aged 6–11 years below the 20th percentile for endurance time, by selected demographic, anthropometric and behavioral characteristics, NNYFS (n = 624)[1], Data source: CDC/NCHS, NNYFS, NOTE: FIPR is family income-to-poverty ratio, 1 Endurance time < 20th percentile for sex- and age-specific cut-points was used to define lowest performers, 2 The relative standard error is >30% but ≤ 40% and may be statistically unreliable. The NHANES guidelines recommend a relative *SE* ≤ 30%., *Significant linear trend, $p < .05$, Error bars represent 95% confidence intervals.

Table 1

Age-Specific Endurance Test Treadmill Protocols, National Health and Nutrition Examination Survey, National Youth Fitness Survey (NNYFS) 2012

		Protocol					
		Ages 6–7		Ages 8–9		Ages 10–11	
Stage	Minutes in a Stage	Speed mph/Speed km/h	Grade (%)	Speed mph / Speed km/h	Grade (%)	Speed mph / Speed km/h	Grade (%)
Warm-up	0–1	2.0/3.22	0.0	2.0/3.22	0.0	2.5/4.02	0.0
1	1–3	2.5/4.02	0.0	2.8/4.63	0.0	3.0/4.83	0.0
2	3–5	2.8/4.51	0.0	3.0/4.83	0.0	3.3/5.31	0.0
3	5–7	3.0/4.83	2.5	3.3/5.31	2.5	3.5/5.63	2.5
4	7–9	3.2/5.15	5.0	3.5/5.63	5.0	5.0/8.05	5.0
5	9–11	3.5/5.63	7.5	4.5/7.24	7.5	5.0/8.05	7.5
6	11–13	4.2/6.76	10.0	4.5/7.24	10.0	5.0/8.05	10.0
7	13–15	4.5/7.24	12.5	4.5/7.24	12.5	5.0/8.05	12.5
8	15–16	4.8/7.72	12.5	5.0	12.5	5.2	12.5
9	16–17	5.0	12.5	5.2	12.5	5.4	12.5
10	17–18	5.2	12.5	5.4	12.5	5.6	12.5
Recovery	18–20	2.0	0.0	2.0	0.0	2.0	0.0

Note. Data source: CDC/NCHS, NNYFS

Table 2

Characteristics of US children aged 6–11 years, NNYFS 2012

	Analytic Sample (*n* = 624)		All NNYFS 2012 Participants Aged 6–11 Years Examined (*n* = 732)	
Characteristics	**Sample Size**	**% (*SE*)**	**Sample Size**	**% (*SE*)**
Sex				
boys	285	47.5 (1.8)	358	51.1 (1.6)
girls	339	52.5 (1.8)	374	48.9 (1.6)
Race and Hispanic origin[†]				
non-Hispanic white	238	54.1 (6.1)	264	52.1 (6.0)
non-Hispanic black	136	12.7 (3.7)	169	13.4 (3.7)
Hispanic	190	22.8 (5.0)	227	23.4 (5.0)
Age groups (years)				
6–7	217	34.4 (1.2)	264	36.4 (1.1)
8–9	201	31.8 (2.1)	227	30.6 (1.8)
10–11	206	33.7 (1.7)	241	33.1 (1.5)
Family income to poverty ratio (%)[*]				
<185	291	45.1 (4.2)	351	46.1 (4.1)
185–349	133	24.9 (2.9)	158	24.7 (2.8)
350	160	29.9 (5.7)	177	29.1 (5.2)
BMI categories[*]				
normal weight/underweight	399	65.5 (2.4)	461	65.2 (2.3)
overweight	115	17.8 (1.2)	126	16.3 (1.0)
obese	110	16.7 (2.1)	144	18.5 (2.1)
Current asthma	624	11.8 (1.8)	732	11.9 (1.6)
Health status				
excellent	290	48.6 (2.8)	336	47.9 (2.7)
very good	199	32.0 (1.5)	227	31.2 (1.5)
good/fair/poor	135	19.4 (2.1)	169	20.9 (2.1)
Household reference person's education[£,*]				
<high school	141	19.8 (2.2)	170	20.6 (2.4)
high school diploma or ged	128	19.5 (2.8)	146	18.8 (2.6)

Characteristics	Analytic Sample (n = 624)		All NNYFS 2012 Participants Aged 6–11 Years Examined (n = 732)	
	Sample Size	% (*SE*)	Sample Size	% (*SE*)
>high school	350	60.7 (3.5)	408	60.5 (3.5)
Physical activity[£,*]				
0–4 days per week	145	22.5 (3.0)	165	21.7 (2.7)
5–6 days per week	115	20.7 (1.5)	138	20.9 (1.4)
7 days per week	362	56.8 (3.2)	426	57.5 (2.9)
TV viewing and computer use[*]				
<=2 hr per day	238	40.8 (3.7)	264	38.9 (3.2)
> 2 hr per day	386	59.2 (3.7)	467	61.1 (3.2)

Note. Data source: CDC/NCHS, NNYFS

[†] Separate estimates are not presented for persons classified as “other”, but are included in the total population estimates. Mexican American persons are included in the “Hispanic” group.

[*] Total sample, sample size is less (BMI, n = 731); (Physical activity, n = 729); (BMI categories, n = 731); (HH reference persons education, n = 724); (Family income to poverty ratio, n = 686)

[£] Analytical sample, sample size is less (Physical activity, n = 622); (HH reference persons education, n = 619); (Family income to poverty ratio, n = 584).

Table 3

Sex- and Age-Specific Mean (95% Confidence Interval) and Selected Percentiles of Maximal Endurance Time (Min:sec) for Children Aged 6–11 Years, NNYFS 2012

			Percentiles				
Characteristics	***n***	**Mean (95% CI)**	**20**	**40**	**50**	**60**	**80**
Age group (years)							
6–7	217	12:10 (11:49–12:31)	11:02	11:38	12:03	12:19	13:06
8–9	201	11:16 (11:00–11:31)	9:22	10:23	11:01	11:33	12:50
10–11	206	10:01 (9:37–10:25)	8:25	9:16	9:42	10:15	11:32
Boys, age group (years)							
6–7	103	12:20 (11:47–12:53)	11:04	11:56	12:14	12:30	13:12
8–9	91	11:25 (10:52–11:59)	9:17	10:22	10:59	11:42	13:36
10–11	91	10:28 (9:51–11:04)[1]	8:36	9:59	10:23	11:16	12:10
Girls, age group (years)							
6–7	114	11:59 (11:45–12:13)	10:57	11:29	11:44	12:09	12:56
8–9	110	11:07 (10:48–11:27)	9:27	10:24	11:01	11:25	12:46
10–11	115	9:38 (9:21–9:55)	8:10	9:03	9:20	9:42	10:57

Note. Data source: CDC/NCHS, NNYFS

[1] Significantly different from girls 10–11 years, $p < .05$.