Published in final edited form as:

J Pediatr. 2012 July ; 161(1): 120–124. doi:10.1016/j.jpeds.2012.01.036.

Standardized Childhood Fitness Percentiles Derived from School-Based Testing

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Abstract

Objective—To develop a statewide school-based program of measuring and reporting cardiovascular fitness levels in children, and to create age- and sex-specific cardiovascular fitness percentile-based distribution curves.

Study design—A pilot study validated cardiovascular fitness assessment with Progressive Aerobic Cardiovascular Endurance Run (PACER) testing as an accurate predictor of cardiovascular fitness measured by maximal oxygen consumption treadmill testing. Schools throughout the state were then recruited to perform PACER and body mass index (BMI) measurement and report de-identified data to a centralized database.

Results—Data on 20 631 individual students with a mean age 12.1 ± 2.0 years, BMI of 21.4 ± 5.1 , and a cardiovascular fitness measured with PACER of 29.7 ± 18.2 laps (estimated maximal oxygen consumption of 36.5 mL/kg/min) were submitted for analysis. Standardized fitness percentiles were calculated for age and sex.

Conclusions—This study demonstrates the feasibility of performing, reporting, and recording annual school-based assessments of cardiovascular fitness to develop standardized childhood fitness percentiles on the basis of age and sex. Such data can be useful in comparing populations and assessing initiatives that aim to improve childhood fitness. Because health consequences of obesity result from both adiposity and physical inactivity, supplementation of BMI measurement with tracking of cardiovascular fitness adds a valuable tool for large-scale health assessment.

An increasing number of children are now classified as obese and fail to meet minimum recommendations for physical activity.¹ Poor physical fitness and obesity are risk factors for type 2 diabetes mellitus (T2DM) and cardiovascular disease.^{2–5} Although obesity increases the risk of illness and other cardiovascular diseases,^{6,7} it has been demonstrated in adults that poor cardiovascular fitness is a risk factor for illness, independent of obesity,⁸ and that

fitness level is a stronger predictor of mortality than obesity.⁹ In both adults^{10,11} and children,^{12,13} it is thought that the beneficial effect of fitness training reflects the combined effects of increased lean mass and reduced fat mass. Increased fitness is associated with reduced disease in adults. In obese children, cardiovascular fitness as measured with maximal oxygen consumption (VO₂ max) and body fat are significant independent predictors of insulin sensitivity and health.¹⁴

From a public health standpoint, assessment of cardiovascular fitness is a vital, yet under performed assessment. Unfortunately, the current standard for assessing cardiovascular fitness, VO₂ max, requires specialized equipment, time, and expert supervision and is therefore not practical for evaluation of large groups of children in school or community settings. A solution for fitness assessment needs to be feasible on a “large-scale,” productive of valid information, and reported in a way that is useful for schools to compare their students and track effectiveness of their programs.

The Progressive Aerobic Cardiovascular Endurance Run (PACER) is a component of the Fitnessgram and consists of a multistage progressive 20-meter shuttle test. The PACER is a valid school-based test of cardiovascular fitness in pediatric populations.¹⁵ We have previously shown in a study of 82 middle school children that the school-based PACER test closely correlates with VO₂ max measured on the treadmill ($r = 0.83$, $P < .0001$), defined as achieving at least two of these 3 criteria: (1) maximal heart rate >200 beats per minute; (2) respiratory exchange ratio (carbon dioxide consumption/oxygen consumption [VO₂]) >1.0 ; and (3) a plateau in VO₂. Additionally, we have shown that PACER correlates closely not only with VO₂ max, but also predictive of insulin resistance, an important marker of health.¹⁶

Increased physical activity in children is a key therapeutic tool for reducing obesity and improving cardiovascular fitness in the school environment.¹⁷ What is lacking, however, is application of a valid and feasible test of cardiovascular fitness (ie, PACER) toward the development of a system by which: (1) fitness can be systematically measured, recorded, and reported throughout the state; (2) reference population ranges to allow for comparison of fitness levels to age- and sex-matched peers; and (3) goals for fitness-improving interventions and progress toward these goals can be measured.

Methods

Children ($n = 82$) from two local middle schools participated in the first phase of this study, to validate school-based cardiovascular fitness testing with laboratory-based cardiovascular fitness testing.¹⁶ Each participant underwent testing at the University of Wisconsin Exercise Science Laboratory after an overnight fast. The Human Subjects Committee approved these procedures, and informed written consent was obtained before initiating the testing protocol. Testing included a physical examination and cardiovascular fitness assessment with VO₂ max. Within 14 days of this testing, the participants performed the PACER at their schools. The gold standard cardiovascular fitness assessment (VO₂ max) is determined with open-circuit spirometry using a progressive treadmill walking protocol to volitional fatigue with a Medical Graphics CPX-D treadmill (St. Paul, Minnesota). The speed of the treadmill was set

initially per the subject's comfort, starting at 0% grade and increasing 2% every minute. Requirements to strictly define whether subjects reached their VO_2 max with this protocol included at least two of these 3 criteria: (1) maximal heart rate >200 beats per minute; (2) respiratory exchange ratio (carbon dioxide consumption/ VO_2) >1.0 ; and (3) a plateau in VO_2 . All the children included in the data analysis met at least two of the 3 criteria. Validation was ultimately determined with a strong correlation between the school-environment PACER test and VO_2 max ($r = 0.83$, $P < .0001$; 95% CI, 0.75–0.89) and PACER and fasting insulin ($r = -0.61$, $P < .001$; 95% CI, -0.72 – 0.45). The intraclass correlation of PACER between repeated measures was 0.86, indicating a high level of test-retest reliability of the PACER.

Once the validation phase of this project was completed, the Department of Public Instruction recruited 131 schools around the state to be included in this project. The University of Wisconsin dedicated a secure website to allow uploading of local school's Fitnessgram data and also provide links to evidenced-based fitness programs and strategies for schools (<http://fitness.pediatrics.wisc.edu>). School staff received training, software, and support for performing Fitnessgram testing, including PACER and body mass index (BMI) determination at the schools, and for data uploading. These data from students were de-identified and securely uploaded from all participating schools in the state. After consultation with our University Human Subjects Committee, this phase of the project was determined to be "exempt from research," because there were no identifiable research subjects and the PACER testing was being performed as a routine part of the school curriculum. A total of 131 middle schools voluntarily submitted fitness data representing 20 631 unique students.

The PACER is a multistage progressive 20-meter shuttle run. Subjects run back and forth along a 20-meter course, and each minute the pace required to run the 20 meters increases. The pace is set from a pre-recorded tape or compact disk. The initial running speed is 8.5 km/hour, and the speed increases by 0.5 km/hour every minute. The test is finished when the subject fails to complete the 20-meter run in the allotted time twice.¹⁸ The PACER is expressed as number of laps completed.

Several methods have been proposed for constructing age-dependent growth charts. Cole and Green proposed a Box-Cox transformation-based semiparametric method for normalizing the data with the Lambda-Mu-Sigma approach.¹⁹ Wei et al recently developed a quantile regression approach for constructing age-dependent growth charts.²⁰ The advantage of the quantile regression method compared with the Lambda-Mu-Sigma method is that the quantile regression approach is more flexible and capable of revealing departures from underlying assumptions of parametric models.

The non-parametric quantile regression approach on the basis of B-splines was used to construct the reference growth charts for fitness and BMI. Age- and sex-specific distributions were assumed for PACER and BMI. The linear conditional quantile functions were estimated by Wei et al.²⁰ Estimate of the slope parameter θ was performed by using the computationally efficient simplex algorithm. The quantile regression was performed for male and female subjects separately.

Data from each school were used for constructing the PACER reference growth charts (PACER measurements from 20 631 unique subjects). VO_2 max values were predicted on the basis of PACER, age, and sex with a previously developed prediction model.¹⁶ Earlier estimation of VO_2 max from PACER score with the Leger equation has been validated in American children and adolescents.²⁰ All 20 631 BMI observations were included in the analysis when constructing the BMI reference growth charts. The values of the BMI reference growth charts were compared with the age- and sex-specific percentiles provided by the Center of Disease Control (version May 30, 2000). All analyses were performed with SAS software version 9.2 (SAS Institute, Cary, North Carolina). Multivariate linear regression analysis was conducted to evaluate the association between cardiovascular fitness and BMI, after adjusting for age and sex. The partial correlation co-efficient between PACER and BMI was computed and reported with the corresponding 95% CI.

Results

PACER scores of fitness for 20 631 unique students from a statewide Wisconsin sample were used to develop reference standards shown in Figures 1 and 2 for male and female students aged 8 to 18 years. Children had a mean age of 12.1 ± 2.0 years, BMI of 21.4 ± 5.1 kg/m^2 , and a cardiovascular fitness measured with PACER of 29.7 ± 18.2 laps. The Table demonstrates the BMI distribution and corresponding percentiles of all students from the Wisconsin database compared with the Centers for Disease Control and Prevention BMI percentile curves published in 2000. A total of 131 schools submitted data of 424 districts in the state, thus representing approximately 31% of school districts.

Standardized age-based curves were calculated for fitness on the basis of age and sex and are shown in Figures 1 and 2. Although the lowest percentile curves for fitness are relatively flat, a steady increase in mean aerobic performance is seen as children enter adolescence. On average, girls had a maximum fitness between ages 14 and 15 years, while boys, on average, had a maximum fitness between 15 and 16 years. Both sexes demonstrated a slight decrease after these peaks. Subanalysis by ethnicity was not possible because schools did not provide this information.

After adjusting for sex and age, BMI was significantly negatively correlated with PACER, with a partial correlation of -0.39 and a 95% CI ranging from -0.41 to -0.38 . When stratified by sex, the partial correlation between BMI and PACER after adjusting for age in male students was -0.42 (95% CI, -0.43 — -0.40), whereas the partial correlation in female students was -0.38 (95% CI, -0.40 — -0.36).

Discussion

Poor cardiovascular fitness increases risk for cardiovascular disease, hypertension, and T2DM^{22,23} and improved cardiovascular fitness attenuates these morbidities. As a result, even overweight yet active individuals can have lower risk for T2DM and cardiovascular disease than sedentary normal-weight individuals.^{9,24} Thus, an important public health goal is the improvement of cardiovascular fitness in the population in general, not just in obese persons.²⁵ From a public health standpoint, assessment of cardiovascular fitness is a vital,

yet under-performed assessment. Unfortunately, the current standard for assessing cardiovascular fitness, VO_2 max, requires specialized equipment, time, and expert supervision and is therefore not practical for evaluation of large groups of children in school or community settings. On an individual patient level, a fitness “percentile” ranking derived from a feasible school-based test could be viewed as another important vital sign, with blood pressure, BMI, or waist-circumference. On a public health level, although PACER was originally developed on the basis of criterion-based standards, presentation of these data, as “population-based” percentile curves can also be very useful. While criterion-based standards indicate a level of fitness thought to be associated with health, these percentile curves of population-based fitness assessment allow comparisons of individuals and groups of children across a defined (eg, statewide) population. Population-based may also be viewed as continuous rather than dichotomous (criterion-based “healthy” or “non-healthy”), which may provide more information about children at lower percentiles. Such population-based percentile distribution curves can be useful for public health cross-sectional assessment and prospective evaluation of interventions.

Fitness testing is a common component of most physical education programs and appropriately receives attention because of the strong link between poor fitness and chronic disease in adults. From a public health standpoint for children, schools are an important vehicle for assessing childhood health and fitness.²⁶ In recent years, a few states have passed legislation to adopt youth fitness testing with PACER.²⁷ Reporting of these test results to generate population-based standards as presented in this paper is important and can be useful in tracking changes in large cohorts of children. This purpose highlights an important difference between “criterion-based” and “population-based” standards for fitness testing. Criterion-based standards are set on the basis of how the score relates to an appropriate reference value.¹⁸ Fitnessgram was introduced with criterion standards in 1987,²⁵ and older values likely do not reflect current norms. In contrast, yearly reporting and generation of population-based references provide a description of current trends and comparisons of groups within populations. Along these lines, Eisenmann re-analyzed National Health and Nutrition Examination Survey data from 1999 to 2002 and produced population-based fitness curves for children.²¹ We present data with a larger, current, and school-based cohort, to produce fitness percentiles for Wisconsin children. This approach could allow states, large school districts, or other large-scale projects to compare various populations.

This description of aerobic performance percentiles suggests important patterns in the development of childhood obesity and poor fitness. While cross-sectional, these data indicate that the level of fitness associated with the lowest percentiles appears to remain at a consistent level of aerobic performance without much improvement with advancing age. In time, one can envision that annual data gathering to generate these population fitness performance percentile curves could be an important tool for documenting change in fitness levels at the public health level.

This report has potential limitations. These population-based fitness percentile curves provide limited information about health implications for an individual child. An important next step would be to more closely link fitness percentiles with health outcome measurements. Another potential limitation of this study is that the sample may not be

sufficiently representative of all students in our state. Although we cannot guarantee that our sample is representative of all student populations, the relatively large size and the geographic and sociodemographic coverage in the sample helps to support the validity of our findings. One school from each of the 131 school districts submitted data (of a total of 424 districts in the state), thus representing approximately 31% of districts. These include urban and rural schools that are geographically distributed in all sectors of the state. According to records at the Wisconsin Department of Public Instruction, the schools also represent high and low socioeconomic status distribution according to percentage of students who qualify for free or reduced lunch.

Establishing these reference percentiles allows schools, which vary geographically and demographically, to compare fitness of their students with others in the state and enable year-by-year tracking of the fitness profiles of large numbers of students now participating in statewide school-based initiatives to improve fitness. Although most pediatricians would agree that both fitness and fatness are important health indicators to address, widespread assessment, reporting, and tracking of childhood fitness remains limited. The feasibility and value of school-based PACER testing suggest that assessment of cardiovascular fitness could be added to BMI as an informative “vital sign” to be obtained on all children in an era of increasing obesity-and poor fitness-related morbidity.

Acknowledgments

Supported by the University of Wisconsin, Wisconsin Partnership Program, which had no involvement in the design, data collection, or analysis.

Glossary

BMI	Body mass index
PACER	Progressive Aerobic Cardiovascular Endurance Run
T2DM	Type 2 diabetes mellitus
VO₂	Oxygen consumption
VO₂ max	Maximal oxygen consumption

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Figure 1.

PACER growth chart for male students. The vertical axis on the right shows the estimated $\text{VO}_2 \text{ max}$ values with an equation previously developed.¹⁶

Figure 2. PACER growth chart for female students. The vertical axis on the right shows the estimated VO_2 max values with an equation previously developed.¹⁶

Table

Summary of PACER and BMI percentiles

Age, years	Percentile	PACER, # laps (WPD)		BMI, kg/m ² (WPD)		BMI, kg/m ² (CDC)	
		Male	Female	Male	Female	Male	Female
8	5th	8	7	14.5	14.2	13.9	13.6
	25th	10	9	16.1	15.9	14.9	14.9
	50th	13	12	17.7	18.0	16.0	16.0
	75th	21	16	20.9	21.0	17.3	17.6
	95th	33	24	27.8	26.7	20.5	21.2
9	5th	8	8	14.7	14.4	14.1	13.9
	25th	11	10	16.5	16.5	15.3	15.3
	50th	16	14	18.3	18.9	16.4	16.6
	75th	27	21	21.9	22.3	17.9	18.3
	95th	40	30	28.4	28.8	21.6	22.4
10	5th	9	9	14.9	14.7	14.4	14.2
	25th	13	12	16.8	17.0	15.7	15.7
	50th	21	17	18.9	19.6	16.9	17.1
	75th	33	25	22.8	23.2	18.6	19.0
	95th	47	37	29.1	30.2	22.6	23.5
11	5th	10	10	15.2	15.2	14.7	14.6
	25th	15	14	17.3	17.6	16.2	16.2
	50th	25	20	19.5	20.2	17.5	17.8
	75th	40	30	23.5	23.9	19.3	19.8
	95th	55	43	30.1	31.2	23.7	24.7
12	5th	12	11	15.6	15.7	15.2	15.0
	25th	19	15	17.8	18.1	16.7	16.8
	50th	31	23	20.0	20.7	18.1	18.4
	75th	47	34	24.1	24.3	20.0	20.6
	95th	62	48	31.0	31.8	24.7	25.7
13	5th	14	12	16.0	16.3	15.7	15.5
	25th	22	17	18.3	18.7	17.3	17.3

Age, years	Percentile	PACER, # laps (WPD)		BMI, kg/m ² (WPD)		BMI, kg/m ² (CDC)	
		Male	Female	Male	Female	Male	Female
14	50th	36	25	20.5	21.1	18.8	19.0
	75th	52	38	24.5	24.6	20.8	21.3
	95th	68	51	32.0	32.3	25.6	26.7
	5th	16	12	16.5	16.9	16.2	16.0
	25th	25	17	18.8	19.2	17.9	17.9
15	50th	41	27	21.1	21.5	19.5	19.6
	75th	57	40	24.8	24.9	21.6	22.0
	95th	72	52	32.9	33.0	26.4	27.7
	5th	17	12	17.0	17.4	16.8	16.5
	25th	27	17	19.4	19.7	18.6	18.4
16	50th	43	27	21.6	21.9	20.2	20.2
	75th	59	40	25.1	25.4	22.3	22.6
	95th	75	52	33.7	34.1	27.2	28.5
	5th	17	11	17.6	17.9	17.4	17.0
	25th	26	16	20.0	20.2	19.2	18.9
17	50th	42	25	22.1	22.5	20.9	20.7
	75th	59	38	25.2	26.1	23.1	23.1
	95th	75	52	34.1	35.8	27.9	29.2
	5th	16	9	18.0	18.1	18.0	17.4
	25th	22	13	20.5	20.7	19.8	19.3
18	50th	38	22	22.6	23.2	21.5	21.1
	75th	56	35	25.2	27.3	23.8	23.6
	95th	72	50	34.2	38.7	28.6	30.0
	5th	14	7	18.5	18.2	18.5	17.7
	25th	18	11	21.0	21.0	20.4	19.6
19	50th	33	18	23.2	23.9	22.2	21.4
	75th	52	31	25.2	28.5	24.5	24.0
	95th	69	49	33.9	40.1	29.3	30.6

WPD, Wisconsin Partnership Statewide Fitness Database (2008–2010); CDC, Center for Disease Control and Prevention (May 30, 2000).