One-Mile Run Performance and Cardiovascular Fitness in Children

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Background: Endurance run tests are administered in schools to assess cardiovascular fitness, defined in the laboratory as maximum oxygen consumption.

Objective: To examine the validity of this concept, assessing the influences of body fat and maximum values of oxygen consumption per unit time, stroke volume, heart rate, and arteriovenous oxygen difference on 1-mile (1.6-km) run time in healthy sixth-grade boys.

Study Design: Subjects were 36 boys with a mean (SD) age of 12.2 (0.5) years. The relationship was examined between body fat content (estimated by skinfold measurements) and maximum oxygen consumption per kilogram and cardiac variables (during maximum cycle testing) with 1-mile run velocity.

Results: Body fat content and maximum oxygen consumption per kilogram (independent of body fat) accounted for 31% and 28% of the variance in run velocity, respectively. Stroke volume was the only component of maximum oxygen consumption that related to run performance.

Conclusions: These findings suggest that cardiovascular fitness and body fat content contribute equally to 1-mile run time in healthy boys and together account for only 60% of the variance in performance on this endurance fitness test. Consequently, 1-mile run performance in children may not serve as a strong indicator of cardiovascular fitness.


Editor’s Note: I wonder how adults would fare in these tests, especially the skill and muscle strength variables.

Catherine D. DeAngelis, MD

SCHOOL-BASED physical fitness test batteries traditionally include endurance performance (such as the 1-mile [1.6-km] run) as a field indicator of “cardiovascular fitness,” defined as maximum oxygen consumption ($V_{O2\text{max}}$). This testing has been based on a strategy of promoting cardiovascular fitness for its positive health outcomes. Studies in adult populations indicate that cardiovascular fitness and regular physical activity are associated with a lower risk for coronary artery disease, hypertension, obesity, and other chronic illnesses. Early promotion of physical fitness and activity in children has been considered an optimal strategy for preventing these lifelong diseases. According to this concept, then, children with poor cardiovascular fitness scores should be identified by inferior performance on endurance fitness tests and enrolled in remedial exercise programs.

The expectation that a child’s 1-mile run time should reflect his or her $V_{O2\text{max}}$, as determined on laboratory exercise testing, has both a conceptual and empirical basis. Values of $V_{O2\text{max}}$ indicate the functional limits of the oxygen delivery chain, critical for providing an aerobic energy source necessary for distance performance. Moreover, correlations between $V_{O2\text{max}}$, expressed relative to body weight, and 1-mile run time in studies of children have been moderately high ($r = -0.65$ to $-0.75$).

Adiposity, however, negatively influences both distance run time (by the excess “baggage” that must be transported) and $V_{O2\text{max}}$ per kilogram (acting as a metabolically inert load in the denominator). Not unexpectedly, then, evidence exists that body fat content is responsible for a significant proportion of the relationship observed between distance run performance and $V_{O2\text{max}}$ expressed per kilogram of body mass. Moreover, $V_{O2\text{max}}$ and body fat together typically explain only a portion of the variability in distance run times in children, suggesting that other fac-

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SUBJECTS AND METHODS

A total of 40 sixth-grade boys (mean [SD] age 12.2 [0.3] years) from the same school volunteered to perform a timed 1-mile run and maximum cycle ergometry test. To assure a wide range of fitness in the study population, 10 subjects were selected from each quartile of finishers in a 1-mile run conducted previously as part of routine school physical education class testing. Four subjects did not complete both laboratory and field testing, and the remaining 36 boys served as the study group.

All subjects were healthy and taking no medications that would influence cardiorespiratory fitness. On a questionnaire, 14 of the 36 indicated that they had experienced a voice change and/or appearance of facial and pubic hair, indicative of early puberty. Twenty-four (67%) had been participating in community sports teams (soccer, basketball), but none was involved in formal aerobic training.

Cycle testing was performed in an air-conditioned laboratory (temperature, 19°C–21°C). Subjects were asked to avoid strenuous exercise 24 hours before testing. Each consumed 240 mL of a sport drink 1 hour before cycle testing. The staff members conducting the cycle testing were unaware of the previous 1-mile run quartile ranking of the subjects.

Height and weight were recorded without shoes, and body surface area was estimated by the DuBois formula. Scapular and triceps skinfolds on the right side were determined in triplicate to the nearest 0.1 mm and averaged using standard techniques. Percent body fat was then estimated from average skinfold measurements using equations developed by Slaughter et al.

Subjects exercised to exhaustion in the upright position on a cycle ergometer. Pedaling rate was maintained at 50 rpm, with initial and incremental 3-minute workloads of 25 W. Subjects were encouraged to perform to exhaustion. The test was terminated when the subject could no longer sustain the pedaling rate.

Heart rate was measured by electrocardiogram. Gas exchange variables were determined using standard open circuit spirometry with a Q-Plex Cardio-Pulmonary Exercise System (Quinton Instrument Company, Seattle, Wash). Peak oxygen consumption per unit time was defined as the mean of the 2 greatest values in the final minute of exercise. Peak oxygen consumption per unit time was considered indicative of $\text{VO}_2\text{max}$ if subjects displayed subjective signs of exhaustion (hyperpnea, discomfort) and maximum heart rate exceeded 190 bpm and/or maximum respiratory exchange ratio was more than 1.00.

Stroke volume was estimated using Doppler echocardiography. Velocity of blood in the ascending aorta was measured with a 1.9-MHz continuous wave transducer directed from the suprasternal notch. The velocity time integral was recorded by automatic integration of the 3 to 10 curves with the highest values and crisp spectral envelopes. Aortic cross-sectional area was calculated from measurement of the diameter of the ascending aorta at the sinotubular junction (inner edge to inner edge) by 2-dimensional echocardiography while subjects were resting in a seated position.

Maximum stroke volume was estimated as the product of the aortic root cross-sectional area and mean velocity time integral value recorded during the final 30 seconds of exercise. Maximum stroke volume multiplied by heart rate provided maximum cardiac output. Maximum arteriovenous oxygen difference was calculated by dividing $\text{VO}_2\text{max}$ by maximum cardiac output.

One-mile run times were recorded during testing on a measured, level outdoor grass course. The subjects had all previously performed 1-mile testing on this course, and each had spent 2 sessions of pacing instruction and practice. A 10-minute stretch and warm-up period was led by a physical education specialist immediately prior to testing. The entire group ran simultaneously on a day that was cool with low humidity. Finish times were converted to average run velocity in meters per second (m/sec).

The relative contributions of percent body fat and oxygen consumption per unit time per kilogram to 1-mile run speed were assessed by stepwise multiple regression analysis. The relationship of maximum cardiac output, maximum stroke volume, maximum heart rate, and maximum arteriovenous oxygen difference to 1-mile run velocity were assessed by Pearson product moment correlation coefficients. Statistical significance was defined as $P < .05$.

Informed consent and assent was obtained from the parents and children, respectively. This study was approved by the institutional review board of the Baystate Medical Center, Springfield, Mass.

The development of Doppler echocardiography, a noninvasive technique that estimates stroke volume during exercise, provides this opportunity. Values for maximum cardiac output, derived by the product of stroke volume and heart rate, by this safe, nonintrusive method have been found to be both valid and reliable in children and adults.

Using Doppler ultrasound and gas exchange measurements of $\text{VO}_2\text{max}$, this study examined the relationships of anthropometric and cardiovascular variables to 1-mile run performance in 12-year-old boys to address 2 questions: (1) What is the magnitude of the contribution of true physiologic cardiovascular fitness (oxygen consumption per unit time per kilogram, independent of body fat) to 1-mile run performance in a group of children with a wide range of fitness? (2) What is the relative importance of maximum stroke volume, heart rate, and maximum cardiac output to 1-mile run performance in boys of this age?
rate, and arteriovenous oxygen difference (the components of \( \dot{V}_{\text{O}_2}\text{max} \)) in determining endurance capacity in children?

The answers to these questions have substantial bearing on the interpretation of endurance tests routinely conducted in the schools for assessment of health-related fitness. Specifically, interventions to improve low cardiovascular fitness and decrease excess body fat, both independent determinants of distance run performance, are different. As noted by Cureton et al., it is "misleading and may be physically and psychologically harmful to inform overweight children that they have poor cardiorespiratory capacity, based on poor distance running performance, if the primary problem is overfatness."

The average 1-mile run time of the boys in this study, 9:07, is comparable to, but somewhat greater than, the mean value of 8:22 reported in school fitness tests of 12-year-old boys in the United States.16 This difference may reflect the higher body fat content of our subjects, who had a mean skinfold sum of 21.2 mm compared with 17 mm in population studies of boys this age.15

The mean value of \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram of 47.2 mL/kg per minute is consistent with those previously described for boys in this age group.10 Similarly, the average maximum cardiac index of 11.98 L/min per m falls at the upper range of normal values (9-12 L/min per m) reported in other pediatric studies.16 The study population can therefore be considered representative of 12-year-old boys in average level of cardiovascular fitness.

The study cohort was purposefully selected to be heterogeneous in endurance performance capabilities. This was indicated by 1-mile run times ranging from 7:00 to 13:12, with a mean velocity of 3.00 (0.48) m/sec (range, 2.02-3.81 m/sec).

All subjects except 2 satisfied criteria for \( \dot{V}_{\text{O}_2}\text{max} \) during cycle testing. In both cases it was the opinion of the testing staff that a true exhaustive effort had been achieved. Mean \( \dot{V}_{\text{O}_2}\text{max} \) was 47.0 (5.8) mL/kg per minute, with a range of 35.1 to 56.7 mL/kg per minute. Mean (SD) maximum heart rate was 198 (10) bpm and maximum respiratory exchange ratio was 1.06 (0.04).

Measurements of cardiac variables at maximum exercise were obtained on all subjects. Average maximum cardiac output relative to body surface area (cardiac index) was 11.98 (2.33) L/min per m. Mean value for maximum stroke index was 61 (11) mL/m and calculated arteriovenous oxygen difference was 13.0 (2.5) mL/100 mL.

The correlation coefficient between \( \dot{V}_{\text{O}_2}\text{max} \) expressed per kilogram of body mass and 1-mile run velocity was 0.77 (P<.05). Zero-order correlation coefficients for body fat content, maximum cardiac index, maximum stroke index, maximum heart rate, and maximum arteriovenous oxygen difference vs 1-mile run velocity are listed in the Table. Significant correlations were observed for only 3 (percent body fat, maximum cardiac index, and stroke index), with correlation coefficients of −0.56, 0.41, and 0.39, respectively. No statistically significant association was seen between 1-mile run velocity and either maximum heart rate or maximum arteriovenous oxygen difference.

A negative relationship was observed between percent body fat and \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram (\( r = -0.73 \)). Multiple regression analysis demonstrated that percent body fat and \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram together accounted for 60% of the variance in 1-mile run velocity. With percent body fat entered initially in the regression model, fat content and \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram accounted for 31% and 28%, respectively, of 1-mile run velocity variance. Thus, 40% of the variance was unexplained by body fat or true cardiovascular fitness.

### RESULTS

Mean (SD) height and weight of the subjects were 153 (9) cm and 45.6 (10.1) kg, respectively. Average sum of scapular and triceps skinfolds was 21.2 (9.1) mm and average body fat content was 19.4% (6.5%) body mass. The leanest and most obese boys had 11.6% and 34.8% body fat, respectively. Average 1-mile run time was 9:07 (range, 7:00-13:12), with a mean velocity of 3.00 (0.48) m/sec (range, 2.02-3.81 m/sec).

All subjects except 2 satisfied criteria for \( \dot{V}_{\text{O}_2}\text{max} \) during cycle testing. In both cases it was the opinion of the testing staff that a true exhaustive effort had been achieved. Mean \( \dot{V}_{\text{O}_2}\text{max} \) was 47.0 (5.8) mL/kg per minute, with a range of 35.1 to 56.7 mL/kg per minute. Mean (SD) maximum heart rate was 198 (10) bpm and maximum respiratory exchange ratio was 1.06 (0.04).

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### TABLE

<table>
<thead>
<tr>
<th>Variable</th>
<th>Run Velocity Variance</th>
<th>P</th>
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<tbody>
<tr>
<td>( \dot{V}_{\text{O}_2}\text{max} ), mL/kg per minute</td>
<td>0.77</td>
<td>&lt;.01</td>
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<tr>
<td>Body fat, %</td>
<td>0.58</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>( Q_{\text{max}} ), L/min</td>
<td>0.41</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>( SV_{\text{max}} ), mL</td>
<td>0.39</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Maximum arteriovenous oxygen difference, mL/dl</td>
<td>−0.14</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Maximum heart rate, beats per min</td>
<td>0.21</td>
<td>&gt;.05</td>
</tr>
</tbody>
</table>

*\( \dot{V}_{\text{O}_2}\text{max} \) indicates maximum oxygen consumption; \( Q_{\text{max}} \), maximum cardiac output; BSA, body surface areas; and \( SV_{\text{max}} \), maximum stroke volume.

### COMMENT

The average 1-mile run time of the boys in this study, 9:07, is comparable to, but somewhat greater than, the mean value of 8:22 reported in school fitness tests of 12-year-old boys in the United States.14 This difference may reflect the higher body fat content of our subjects, who had a mean skinfold sum of 21.2 mm compared with 17 mm in population studies of boys this age.15

The mean value of \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram of 47.2 mL/kg per minute is consistent with those previously described for boys in this age group.10 Similarly, the average maximum cardiac index of 11.98 L/min per m falls at the upper range of normal values (9-12 L/min per m) reported in other pediatric studies.16 The study population can therefore be considered representative of 12-year-old boys in average level of cardiovascular fitness.

The study cohort was purposefully selected to be heterogeneous in endurance performance capabilities. This was indicated by 1-mile run times ranging from 7:00 to 13:12, and reflected in the range of \( \dot{V}_{\text{O}_2}\text{max} \) from 35.1 to 56.7 mL/kg per minute. Similarly, the differences in body fat content in these subjects provided a reasonably representative sample of normal variability among boys of this age group in the general population. Mean (SD) body fat content was 19.3% (6.6%) of body weight (range, 11.6%-34.8%).

The findings of this study provide 2 important insights into the relationship of cardiovascular fitness and 1-mile run time in an average cross-section of 12-year-old boys.

### CARDIOVASCULAR FITNESS

Defined as maximum oxygen uptake relative to body size, cardiovascular fitness plays a limited role in the determination of endurance running capacity. While \( \dot{V}_{\text{O}_2}\text{max} \) per kilogram was closely linked to 1-mile run time (\( r = 0.77 \)), half of this relationship was accounted for by the influence of body fat. Consequently, true cardiovascular fitness was responsible for only 28% of variance in run speed. These findings are consistent with the expectations of Cureton et al., who found that only a quarter of variance in endurance performance in children can be explained by cardiovascular fitness.
Body fat content was linked to run speed ($r = -0.56$) and was responsible for 31% of performance variance. This finding mimics that of previous reports, which have consistently indicated the importance of body composition in distance run performance in children. Correlation coefficients between percent body fat and distance performance in these studies have generally ranged from 0.40 to 0.55, but correlation coefficients as high and low as 0.72 and 0.18 have been reported. The penalty paid for transporting excessive fat during such events was highlighted by Watson, who demonstrated that adolescent boys decreased distance covered in a 12-minute walk by an average of 46 yards (41.4 m) for each 1% increase in body fat.

Cureton et al examined the relationship of body fat, cardiovascular fitness, and 50-yd (45-m) sprint speed on 1-mile run time in children aged 7 to 12 years. The marker of cardiovascular fitness in that study was VO$_2$max expressed per kilogram of lean body mass, which was considered to be largely independent of body fat. Maximum oxygen consumption per kilogram of lean body mass related to 1-mile run time with a correlation coefficient of −0.40, almost identical to that observed between 1-mile run velocity and maximum stroke volume in this study. Percent body fat and 50-yd (45-m) dash time were the most important determinants of 1-mile time, with only a minor contribution by VO$_2$max per kilogram of lean body mass.

The concept that other nonaerobic factors might be important in determining distance performance in children is well-supported by previous studies. Mahon et al assessed factors influencing 3-km running performance in 10-year-old boys. Correlation coefficients of run time with sum of 6 skinfolds and VO$_2$max per kilogram were 0.72 and −0.61, respectively. Stepwise multiple regression analysis indicated that percent VO$_2$max at 8 km/h treadmill running (fractional use) and vertical jump (a measure of explosive muscle power) explained 83% of the variance in run time.

Palgi et al reported correlation coefficients of −0.73 and 0.55 for VO$_2$max per kilogram and percent body fat with 2-km run time in 10- to 14-year-old boys and girls. Multiple regression analysis indicated that anaerobic capacity (as measured by a 30-second all-out cycle test) accounted for 60% of the variance in run time and VO$_2$max per kilogram was responsible for an additional 7%.

The role of nonaerobic factors in influencing endurance performance in children is further supported by the observation that endurance fitness improves dramatically during childhood without a concomitant increase in size-relative VO$_2$max. A typical 5-year-old boy can run 1 mile in 13:46, while the average 15-year-old boy will finish in 7:14. Both, however, can be expected to have similar values for VO$_2$max per kilogram.

### MAXIMUM STROKE VOLUME

Related to body size, maximum stroke volume is the sole component of cardiovascular fitness (VO$_2$max) that influences endurance performance. Within this population of nonathletically trained children, no relationship was observed between arteriovenous oxygen difference and 1-mile run performance ($r = -0.14, P > 0.05$). This suggests that factors such as blood hemoglobin content, muscle aerobic enzyme capacity, and skeletal muscle fiber type, all which have been associated with endurance performance in trained adult endurance athletes, cannot be expected to influence 1-mile run times among school-aged children.

It follows that factors that influence maximum stroke volume are important in defining the contribution of VO$_2$max to endurance performance. The relative importance of preload, myocardial contractility, and afterload to maximum values of stroke volume in children have not been established. Based on observations in both child and adult endurance athletes, however, the role of augmented diastolic filling during high-intensity exercise may be important.

The results of this study indicate that the finish time for a 1-mile run cannot be confidently interpreted as indicative of a child’s level of cardiovascular fitness. However, while the contribution of cardiovascular fitness to 1-mile run time in children may be limited, this study does not necessarily imply a lack of value of endurance testing as an indicator of health-related fitness. Adiposity in older children constitutes a high risk for future adult fitness, and a combination of cardiovascular fitness and body fat content were responsible for 60% of the variance in 1-mile run times. Poor performance on such tests may therefore be assumed to identify children who are at risk for health problems based on low cardiovascular fitness and/or excessive body fat.

Assuming that low cardiovascular fitness, independent of body fat, constitutes a health risk, regression equations have been developed to adjust 1-mile run/walk times in children for body fat content (estimated by skinfold measurements). Cureton et al found that such adjustments significantly altered the test rankings in more than 10% of 12-year-old children. However, contrary to these findings and those of this study, Pate et al found low correlations between run times and skinfold thicknesses in children aged 6 to 18 years ($r = -0.16$ to $-0.27$), indicating that such adjustment was not necessary.

In summary, this study indicates that true cardiovascular fitness (VO$_2$max per kilogram, independent of body fat) accounts for only approximately a quarter of the variance in 1-mile run times in 12-year-old boys. Among the physiological components of VO$_2$max, stroke volume is the only factor associated with run performance. The magnitude of influence of cardiovascular fitness on endurance performance is not dissimilar to that of body fat content. Thus, finish time in a 1-mile run test should be expected to provide information regarding body composition as much as cardiovascular fitness. True cardiovascular fitness and body composition combined contribute to 60% of run variance, suggesting that nonaerobic factors (anaerobic capacity, skill, and muscle strength) are significant determinants of endurance performance in children.

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