Development and Validation of a Regression Model to Estimate VO\textsubscript{2}\text{peak} From PACER 20-m Shuttle Run Performance

Matthew T. Mahar, Gregory J. Welk, David A. Rowe, Dana J. Crotts, and Kerry L. McIver

Background: The purpose of this study was to develop and cross-validate a regression model to estimate VO\textsubscript{2}\text{peak} from PACER performance in 12- to 14-year-old males and females. Methods: A sample of 135 participants had VO\textsubscript{2}\text{peak} measured during a maximal treadmill test and completed the PACER 20-m shuttle run. The sample was randomly split into validation (n = 90) and cross-validation (n = 45) samples. The validation sample was used to develop the regression equation to estimate VO\textsubscript{2}\text{peak} from PACER laps, gender, and body mass. Results: The multiple correlation (R) was .66 and standard error of estimate (SEE) was 6.38 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}. Accuracy of the model was confirmed on the cross-validation sample. The regression equation developed on the total sample was: VO\textsubscript{2}\text{peak} = 47.438 + (PACER*0.142) + (Gender[m=1, f=0]*5.134) – (body mass [kg]*0.197), R = .65, SEE = 6.38 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}. Conclusions: The model developed in this study was more accurate than the Leger et al. model and allows easy conversion of PACER laps to VO\textsubscript{2}\text{peak}.

Key Words: adolescents, aerobic capacity, cross-validation, FITNESSGRAM, multiple regression

Aerobic capacity is an important component of youth fitness. Adequate levels of aerobic capacity are associated with a host of health benefits, including a lower risk of obesity, heart disease, diabetes, and hypertension.\textsuperscript{1,2,3} In addition, aerobic capacity in prepubertal children predicts future adiposity.\textsuperscript{4} Because of its central importance to health, cardiorespiratory (aerobic) fitness is one of the key physical fitness indicators used in school physical education programs. The available field tests of aerobic capacity in the FITNESSGRAM\textsuperscript{\textregistered} battery are the PACER (Progressive Aerobic Cardiovascular Endurance Run) and the one-mile run.\textsuperscript{5} The PACER test is the recommended assessment for a number of reasons. It can be conducted indoors or outdoors in a relatively small area, it can be run to
music, and it may be more enjoyable than distance run tests for some participants. In addition, the nature of the PACER test closely resembles the procedures in a maximal graded exercise test. The workload (pace) increases at each stage until the participant reaches a maximal effort and cannot continue. This avoids the problems with pacing that can lead to inaccurate assessments with the one-mile run.

The equation used in the FITNESSGRAM software to estimate aerobic capacity (VO$_2$peak) from the PACER test was published by Leger et al.,$^6$ who developed this model on a sample of 188 males and females ages 8 to 19 years and reported a correlation of .71 between estimated and measured VO$_2$peak. VO$_2$peak was estimated from maximal speed attained during the 20-meter shuttle run, age, and the speed-by-age interaction. They measured VO$_2$peak by retroextrapolation immediately after a maximal test.

The accuracy of the Leger et al.$^6$ prediction model has been examined by several researchers,$^7$–$^{14}$ but few attempts have been made to develop a more accurate model. Development of a more accurate model may be necessary for several reasons. First, Leger et al. did not report the number of participants at each gender and age subgroup, so it is not possible to tell from the original publication how well different subgroups are represented. Second, because gender was not entered into the prediction model, Leger et al. did not examine possible differences between males and females. The gender-by-age interaction contributed significantly to prediction for the one-mile run test, and it is possible that differences in running economy and efficiency may also influence performance on the PACER.

Third, the estimates of VO$_2$peak for low lap scores were based on extrapolated data from the study since the original study population did not have data for these points. Application of a prediction model to populations that are not well represented in the development sample can result in substantial prediction error. Some evidence has suggested that the PACER equation may lead to spurious results for some populations. For example, previous research has demonstrated larger discrepancies in classification agreement between the PACER and the one-mile run among young girls than among boys. In a study by Mahar et al.,$^{15}$ classification agreement was 66% for 10- to 11-year-old girls and 83% for boys of the same age. In a similar study, Vincent et al.$^{16}$ reported classification agreement of 55% for 5th grade girls and 83% for 5th grade boys. While it is possible that classification agreement may be due to differential performance on the one-mile run, the frequent reports of problems with the PACER for young girls deserves further attention.

The purpose of this study was to develop and cross-validate a regression model to estimate VO$_2$peak from PACER performance, gender, and body mass or body mass index (BMI) in 12- to 14-year-old males and females. In addition, the Leger et al.$^6$ model was cross-validated to allow comparison of prediction accuracy among the models.

### Methods

#### Participants

Participants included in the analyses were 74 females and 61 males ages 12 to 14 years who were recruited at two sites. Fifty-nine females and 30 males were from North Carolina and 15 females and 31 males were from Iowa. The study was approved by the institutional review boards of East Carolina University and Iowa State University. Written informed consent was obtained from parents and assent
was obtained from participants. Physical characteristics of the participants are presented in Table 1. Participants with standardized residual scores greater than 3.0 were identified as outliers and were deleted from the analyses (n = 2).

**Validation and Cross-Validation Samples**

Validation and cross-validation samples were formed to allow cross-validation of the newly developed prediction equation. Approximately one-third of the participants from each site were randomly selected for the cross-validation group (n = 45). The remaining participants formed the validation group (n = 90). No statistically significant mean differences (p > .05) were found between females in the validation and cross-validation groups. Males in the cross-validation sample were significantly (p < .05) heavier than males in the validation sample (see Table 1).

**Procedures**

Prior to testing, all participants were habituated to treadmill exercise. Each participant underwent a graded exercise test to volitional exhaustion on a Trackmaster (model TMX425C, Carrollton, TX) or Quinton (model Q65, Bothell, WA) treadmill to determine peak oxygen consumption (VO2peak). For females, the speed of the treadmill was increased to 5.0 mph within the first minute. For two females a speed of 4.2 mph was used to assure safety. This speed was maintained for the remainder of the test. Speed was increased to 5.5 mph for three females and to 6 mph for one female. For males, speed was increased to 5.5 mph within the first minute and maintained for the remainder of the test. For eight males, a speed of 5 mph was

<table>
<thead>
<tr>
<th>Variable</th>
<th>Validation sample</th>
<th>Cross-validat. sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females (n = 49)</td>
<td>Males (n = 41)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>13.2 ± 0.9</td>
<td>13.0 ± 0.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160.1 ± 5.7</td>
<td>162.1 ± 5.7</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>52.5 ± 11.8</td>
<td>53.1 ± 10.8</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>20.4 ± 4.2</td>
<td>20.1 ± 3.4</td>
</tr>
<tr>
<td>Percent fat (%)</td>
<td>27.8 ± 9.4</td>
<td>21.9 ± 9.5</td>
</tr>
<tr>
<td>PACER (# laps)</td>
<td>30.3 ± 16.4</td>
<td>45.5 ± 18.0</td>
</tr>
<tr>
<td>Max PACER speed (km·hr⁻¹)</td>
<td>10.1 ± 0.9</td>
<td>10.9 ± 1.0</td>
</tr>
<tr>
<td>VO2peak (ml·kg⁻¹·min⁻¹)</td>
<td>42.0 ± 6.9</td>
<td>49.3 ± 8.5</td>
</tr>
<tr>
<td>Max heart rate (b·min⁻¹)</td>
<td>203 ± 8.0</td>
<td>202 ± 8.1</td>
</tr>
<tr>
<td>Maximal RER</td>
<td>1.14 ± 0.07</td>
<td>1.11 ± 0.05</td>
</tr>
<tr>
<td>Max treadmill time (min)</td>
<td>5.7 ± 1.7</td>
<td>6.6 ± 2.1</td>
</tr>
</tbody>
</table>

* Statistically significant (p < .05) difference between validation and cross-validation samples.
chosen to assure safety. Speed was increased to 6 mph for five males, to 6.5 mph for 1 male, and to 7 mph for 2 males. At the beginning of the second minute, the treadmill grade was increased to 2%. Every minute thereafter, the treadmill grade was increased by an additional 2% until the participant could no longer continue.

VO$_2$ was assessed using a Consentius Technologies-ParvoMedics TrueMax 2400 metabolic measurement system (Salt Lake City, UT). Prior to the test, the cart was calibrated using known sample gases. VO$_2$peak was accepted as a maximal index if two of the following three conditions were satisfied: the participant was habituated to the test procedures and environment and showed signs of intense effort (e.g., hyperpnea, facial flushing and grimacing, unsteady gait, sweating);$^{17}$ peak heart rate reached a value at least 95% of maximal heart rate as predicted by age; and respiratory exchange ratio (RER) was at least 1.0.$^{18}$ Two participants were eliminated based on inadequate VO$_2$peak tests.

Body mass and height were measured on a balance beam scale (Healthometer, Boca Raton, FL). Body mass index was calculated as body mass (kg) divided by height (m) squared. Skinfolds were measured at the triceps and calf site with Lange (Cambridge, MD) calipers, and percent fat was estimated with the equations of Slaughter et al.$^{19}$

The PACER 20-m multistage shuttle run was administered following standardized procedures.$^5$ Participants ran from one marker to another marker set 20 m apart, while keeping pace with a prerecorded cadence. The cadence was set to music and increased every minute. Participants were instructed to keep up with the cadence for as long as possible. The test was terminated when a participant failed to reach the appropriate marker in the allotted time twice or could no longer maintain the pace. The number of laps completed was recorded.

**Estimation of VO$_2$peak**

Multiple linear regression was used in the validation sample to predict VO$_2$peak from the number of laps completed on the PACER, gender, and body mass or BMI. The equations developed on the validation sample were applied to the cross-validation sample. The correlation between measured VO$_2$peak and VO$_2$peak predicted from the equations developed on the validation sample were calculated. Prediction error was assessed with two equations. The standard error of estimate (SEE) was calculated as: $SEE = \sqrt{1 - R^2_{YY'}}$. The cross-validation standard error of estimate (referred to as total error [TE]) was calculated as: $TE = \sqrt{\sum(Y - Y')^2}/N$. For these equations, $Y$ is measured VO$_2$peak and $Y'$ is VO$_2$peak estimated from the equations developed on the validation sample. Comparison of these two error estimates quantifies the effect of systematic overestimation or underestimation on prediction accuracy. Residual scores were correlated with estimated VO$_2$peak to examine prediction bias. The Gender $\times$ PACER laps interaction term was entered into the model, but did not add significantly to the prediction and was thus omitted from the model. Regression was used to demonstrate that the slopes of these equations did not differ from one and the intercepts did not differ from zero.

For comparison, VO$_2$Peak was also estimated by the equation published by Leger et al.$^6$ This is the equation currently used in the FITNESSGRAM program to estimate aerobic capacity. This prediction model is: $VO_2$peak’ = 31.025 + (3.238 * speed in km/h$^{-1}$) – (3.248 * age) + (0.1536 * speed * age), where speed is maximal speed attained on the test and age is in years.
Correlations between measured VO$_2$ peak and the predictor variables are presented in Table 2. The correlation between measured VO$_2$ peak and PACER laps completed was moderate and accounted for 35% of the variance in VO$_2$ peak. A plot of VO$_2$ peak and PACER performance (see Figure 1) revealed a linear relationship. Using FITNESSGRAM standards for VO$_2$ max, 80% of the total sample (78% of females and 82% of males) had values above the criterion-referenced standard. When PACER standards for the number of laps completed were examined, 60% of the total sample (58% of females and 62% of males) had values above the criterion-referenced standard.

Table 2: Zero-Order Correlations Between Measured VO$_2$ peak and Predictor Variables for Validation Group and Total Sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Validation sample ($n = 90$)</th>
<th>Total sample ($N = 135$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACER (# laps)</td>
<td>.59*</td>
<td>.53*</td>
</tr>
<tr>
<td>Gender (1=male, 0=female)</td>
<td>.43*</td>
<td>.44*</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>−.28*</td>
<td>−.30*</td>
</tr>
<tr>
<td>BMI (kg·m$^{-2}$)</td>
<td>−.37*</td>
<td>−.39*</td>
</tr>
</tbody>
</table>

* $p < .05$

Figure 1 — Scatterplot of measured VO$_2$ peak vs. PACER performance in total sample ($N = 135$).

Results

Correlations between measured VO$_2$ peak and the predictor variables are presented in Table 2. The correlation between measured VO$_2$ peak and PACER laps completed was moderate and accounted for 35% of the variance in VO$_2$ peak. A plot of VO$_2$ peak and PACER performance (see Figure 1) revealed a linear relationship. Using FITNESSGRAM standards for VO$_2$max, 80% of the total sample (78% of females and 82% of males) had values above the criterion-referenced standard. When PACER standards for the number of laps completed were examined, 60% of the total sample (58% of females and 62% of males) had values above the criterion-referenced standard.
Table 3  Multiple Regression Models to Estimate VO\(_2\)peak (ml·kg\(^{-1}\)·min\(^{-1}\)) From PACER Laps, Gender, and Body Mass or BMI on Validation Sample and on Total Sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Validation sample ((n = 90))</th>
<th>Total sample ((N = 135))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PACER 1 (Body mass model)</td>
<td>PACER 2 (BMI model)</td>
</tr>
<tr>
<td>Intercept</td>
<td>44.596</td>
<td>47.603</td>
</tr>
<tr>
<td></td>
<td>(37.244, 51.948)*</td>
<td>(39.069, 56.137)</td>
</tr>
<tr>
<td>PACER (# laps)</td>
<td>0.202</td>
<td>0.187</td>
</tr>
<tr>
<td></td>
<td>(0.124, 0.280)</td>
<td>(0.109, 0.265)</td>
</tr>
<tr>
<td>Gender (m=1, f=0)</td>
<td>4.334</td>
<td>4.294</td>
</tr>
<tr>
<td></td>
<td>(1.386, 7.282)</td>
<td>(1.378, 7.210)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>−0.166</td>
<td>−0.197</td>
</tr>
<tr>
<td></td>
<td>(−0.288, −0.044)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg·m(^{-2}))</td>
<td>−0.551</td>
<td>−0.551</td>
</tr>
<tr>
<td></td>
<td>(−0.912, −0.190)</td>
<td></td>
</tr>
<tr>
<td>(R)</td>
<td>.66</td>
<td>67</td>
</tr>
<tr>
<td>(R^2)</td>
<td>.44</td>
<td>.45</td>
</tr>
<tr>
<td>SEE (ml·kg(^{-1})·min(^{-1}))</td>
<td>6.38</td>
<td>6.32</td>
</tr>
</tbody>
</table>

* 95% CI of the regression coefficients are within parentheses under coefficient.
Results of the multiple regression analysis to estimate $\text{VO}_2\text{peak}$ from PACER laps, gender, and body mass or BMI are presented in Table 3. All predictor variables made statistically significant contributions to the prediction of $\text{VO}_2\text{peak}$. For the model with body mass (PACER 1 body mass), 44% of the variance in $\text{VO}_2\text{peak}$ could be explained by the predictor variables. For the model with BMI (PACER 2 BMI), the predictor variables explained 45% of the variance in $\text{VO}_2\text{peak}$.

The accuracy of the models was confirmed when the multiple regression equations developed on the validation sample were applied to the cross-validation sample. Table 4 presents means and standard deviations of measured $\text{VO}_2\text{peak}$ and $\text{VO}_2\text{peak}$ estimated from the regression equations, along with correlations between measured and estimated $\text{VO}_2\text{peak}$, and standard errors of estimate. The mean differences between measured and estimated $\text{VO}_2\text{peak}$ were less than 2.5 ml·kg$^{-1}$·min$^{-1}$ for all models and not statistically significant. The two newly developed regression models had higher correlations and lower standard errors of estimate than the Leger et al. equation. The total error for the two new models was only slightly higher than the $\text{SEEs}$ of 6.3 ml·kg$^{-1}$·min$^{-1}$ in the validation sample.

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean ± SD (ml·kg$^{-1}$·min$^{-1}$)</th>
<th>$r_{yy}$</th>
<th>$\text{SEE}$ (ml·kg$^{-1}$·min$^{-1}$)</th>
<th>TE (ml·kg$^{-1}$·min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-validation sample ($n = 45$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured $\text{VO}_2\text{peak}$</td>
<td>42.6 ± 7.8</td>
<td>.62</td>
<td>6.15</td>
<td>6.83</td>
</tr>
<tr>
<td>PACER 1 body mass</td>
<td>44.8 ± 7.1</td>
<td>.63</td>
<td>6.19</td>
<td>6.84</td>
</tr>
<tr>
<td>PACER 2 BMI</td>
<td>44.9 ± 7.1</td>
<td>.53</td>
<td>6.67</td>
<td>7.30</td>
</tr>
<tr>
<td>Leger et al. (1988)</td>
<td>43.9 ± 7.0</td>
<td>.53</td>
<td>6.67</td>
<td>7.30</td>
</tr>
<tr>
<td>Total sample ($N = 135$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured $\text{VO}_2\text{peak}$</td>
<td>44.4 ± 8.4</td>
<td>.64</td>
<td>6.44</td>
<td>6.51</td>
</tr>
<tr>
<td>PACER 1 body mass</td>
<td>45.2 ± 6.1</td>
<td>.64</td>
<td>6.41</td>
<td>6.48</td>
</tr>
<tr>
<td>PACER 2 BMI</td>
<td>45.2 ± 6.2</td>
<td>.54</td>
<td>6.67</td>
<td>7.03</td>
</tr>
<tr>
<td>Leger et al. (1988)</td>
<td>43.5 ± 6.0</td>
<td>.54</td>
<td>6.67</td>
<td>7.03</td>
</tr>
</tbody>
</table>

The validation and cross-validation samples were combined to allow development of regression equations on the total group. The resulting equations and accompanying statistics are presented in Table 3. This equation did not differ (all regression coefficients and the intercept are within 95% confidence intervals) from the equation developed on the validation sample and is recommended for use. Figures 2 and 3 show plots of measured $\text{VO}_2\text{peak}$ and $\text{VO}_2\text{peak}$ estimated from the regression model with body mass (PACER 1 body mass) and the regression model with BMI (PACER 2 BMI), respectively. Regression analysis indicated that the slopes of the models did not differ from one and the intercepts did not differ.
Figure 2 — Scatterplot of measured VO\textsubscript{2peak} vs. VO\textsubscript{2peak} predicted from PACER performance, gender, and body mass (PACER 1 body mass model) in the total sample (\(N = 135\)). Line of identity is shown.

Figure 3 — Scatterplot of measured VO\textsubscript{2peak} vs. VO\textsubscript{2peak} predicted from PACER performance, gender, and BMI (PACER 2 BMI model) in the total sample (\(N = 135\)). Line of identity is shown.
from zero ($\rho > .05$). The standardized regression coefficients presented in Table 5 demonstrate that PACER performance contributed more to the prediction than other variables in the model.

Figures 4 and 5 present plots of residuals vs. predicted values of VO$_2$peak for the total sample to allow examination of heteroscedasticity of error. The degree of scatter is similar for levels of predicted VO$_2$peak above 35 ml·kg$^{-1}$·min$^{-1}$, indicating that the error is uniform for levels of aerobic capacity above this value. The smaller scatter of points below this value may be due to the small number of participants in the sample with predicted levels of aerobic capacity below this value.

### Table 5 Standardized Regression Coefficients ($\beta$) for VO$_2$peak (ml·kg$^{-1}$·min$^{-1}$) Prediction Models

<table>
<thead>
<tr>
<th>Variable</th>
<th>PACER 1 (Body mass)</th>
<th>PACER 2 (BMI model)</th>
<th>PACER 1 (Body mass)</th>
<th>PACER 2 (BMI model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACER (# laps)</td>
<td>0.454</td>
<td>0.420</td>
<td>0.367</td>
<td>0.326</td>
</tr>
<tr>
<td>Gender (m=1, f=0)</td>
<td>0.255</td>
<td>0.253</td>
<td>0.307</td>
<td>0.295</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>–0.220</td>
<td>–0.249</td>
<td>–0.288</td>
<td>–0.307</td>
</tr>
<tr>
<td>BMI (kg·m$^{-2}$)</td>
<td>–0.249</td>
<td>–0.307</td>
<td>–0.307</td>
<td>–0.307</td>
</tr>
</tbody>
</table>

**Figure 4** — Predicted vs. residuals for PACER 1 (body mass) model.
Discussion

The PACER 20-meter shuttle run has become one of the most widely used field tests of aerobic capacity and is the recommended (default) test for the FITNESSGRAM youth fitness program. While a number of studies have supported the overall utility of the Leger et al. equation used to estimate VO_{2max} in the FITNESSGRAM software, few attempts have been made to cross-validate this prediction model or to develop other PACER prediction models.

In this study, multiple regression equations to estimate aerobic capacity (VO_{2peak}) from PACER performance were developed and cross-validated in a sample of 12- to 14-year-old males and females. Equations were developed with gender and either body mass or BMI in the prediction model. The new equations were shown to be more accurate than the Leger et al. model for our sample of young adolescent youth (ages 12–14). When the total sample is considered, the newly developed equations explained nearly 12% more variance in VO_{2peak} than the Leger et al. model. Another advantage of the present equations is that they use number of laps completed to predict VO_{2peak}, rather than maximal speed attained. This allows easier transformation of the PACER scores to estimate aerobic capacity and is also easier for the practitioner to use and understand. Another advantage of using lap counts instead of maximal speed attained is that it may be possible to make finer distinctions in fitness levels for particular individuals or to better determine changes in aerobic fitness consequent to training.

As noted by Cureton and Plowman, the PACER has evidence of logical validity because the pacing simulates that of the criterion to which it is most often compared—a maximal graded exercise test. The speed is incremented each minute of the PACER and the workload progressively increases until a participant reaches his or her maximal effort. Leger et al. developed the regression equation for the

![Figure 5 — Predicted vs. residuals for PACER 2 (BMI) model.](image-url)
PACER using a diverse sample (188 males and females ages 8 to 19 years). They reported a multiple $R$ between measured and estimated VO$_2$peak of .71 and a standard error of estimate of 5.9 ml·kg$^{-1}$·min$^{-1}$. Although the sample appears to be relatively large, it actually may be quite small for particular age groups. Leger et al. did not provide the number of participants at each age group, but if an equal number of males and females were used for each age and gender subgroup, then only about 8 participants per group would result. Thus, inaccurate estimates of VO$_2$peak could be attained for any specific subgroup.

Concurrent validity evidence for the Leger et al.\(^6\) equation has been acceptable but not exceptionally strong.\(^7\)–\(^{14}\) Liu et al.\(^{11}\) cross-validated the Leger et al. equation on a sample of 12- to 15-year-olds and reported a correlation of .72 and a $SEE$ of 5.4 ml·kg$^{-1}$·min$^{-1}$. Liu et al. also reported the correlation between number of laps completed and measured VO$_2$peak (for all participants $r = .69$, for males $r = .65$, and for females $r = .51$). Barnett et al.\(^9\) also cross-validated the equation of Leger et al. on a sample of 12- to 17-year-old Chinese students ($n = 55$) and reported similar results ($r = .72$, $SEE = 5.4$ ml·kg$^{-1}$·min$^{-1}$). The correlation between measured VO$_2$peak and maximal shuttle run speed attained during the PACER was .74. Van Mechelen et al.\(^{14}\) reported a similar correlation ($r = .76$) between measured VO$_2$peak and the number of stages of the PACER completed for 12- to 14-year-olds. The correlation was .68 for males and .69 for females.

Boreham et al.\(^{10}\) reported correlations between measured VO$_2$peak and the number of laps completed on the PACER for 14- to 16-year-olds. They found $r = .87$ for all 41 participants, $r = .64$ for 23 males, and $r = .90$ for 18 females. On a small sample ($n = 13$) of 10- to 12-year-old males, Anderson\(^7\) reported a correlation of .72 between the PACER and measured VO$_2$peak. A lower correlation ($r = .54$) between PACER and measured VO$_2$peak was reported by Armstrong et al.\(^8\) on 11- to 14-year-old males. In a more recent study, Suminski et al.\(^{13}\) reported correlations between measured and estimated VO$_2$peak of .62 for the total sample. These results are similar to the multiple correlation between measured VO$_2$peak and VO$_2$peak of .65 estimated from the prediction model developed in the current study. The smaller $SEE$ reported by Suminski et al. of 4.71 ml·kg$^{-1}$·min$^{-1}$ for males and 3.10 ml·kg$^{-1}$·min$^{-1}$ for females is directly related to the smaller variability in measured VO$_2$peak. Suminski et al. reported standard deviations of measured VO$_2$peak of 5.8 ml·kg$^{-1}$·min$^{-1}$ for males and 3.0 ml·kg$^{-1}$·min$^{-1}$ for females, compared to 8.3 ml·kg$^{-1}$·min$^{-1}$ for males and 6.9 ml·kg$^{-1}$·min$^{-1}$ for females in the current study.

Comparisons with the validity evidence on the one-mile run is also helpful when evaluating the utility of the PACER test. The size of the relationship between the one-mile run and measured VO$_2$peak is similar to the relationship of the PACER to measured VO$_2$peak found in the current study. Cureton et al.\(^{22}\) provided a thorough analysis of the equation used in the FITNESSGRAM to predict VO$_2$peak from one-mile run performance, age, sex, and BMI. Their sample was much larger ($N = 753$ males and females) and more variable in age (ages 8 to 25). The multiple correlation for this equation was .72, with a $SEE$ of 4.84 ml·kg$^{-1}$·min$^{-1}$. For 11- to 13-year-old participants in the Cureton et al. study, the correlation between measured and estimated VO$_2$peak was .57, which is slightly lower than the correlation of .65 in the current study for 12- to 14-year-olds. The correlation between measured VO$_2$peak and one-mile run time was $-.54$.\(^{22}\)

In the current study, the correlation between PACER laps completed and measured VO$_2$peak was .53. In general, the multiple $R$ and $SEE$ found in the current
study are similar to results reported for the one-mile run. The slightly higher SEE in the current study is partially due to the higher variability in measured VO₂peak (the standard deviation of VO₂peak of the total sample for the current study is 8.4 ml·kg⁻¹·min⁻¹, whereas the SD of VO₂peak for the 11- to 13-year-olds in the Cureton et al. study was 6.6 ml·kg⁻¹·min⁻¹). The large variability in measured VO₂peak in the current study probably allows for accurate representation of the type of participants for whom the equation will be used.

In summary, regression equations to estimate VO₂peak from PACER performance, gender, and body mass or BMI were developed and cross-validated in a heterogeneous sample of 12- to 14-year-old males and females. The newly developed equations provide more accurate estimates of VO₂peak than the Leger et al. model, which is the model currently used in the FITNESSGRAM software. Prediction accuracy of the newly developed models appears to be similar to that of the one-mile run, which is also an available test option for adopters of the FITNESSGRAM. The limitation of the equation is that it is appropriate only for 12- to 14-year-old males and females. Prediction models for other age groups should be developed and evaluated.

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References


