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Pediatric Exercise Science, 2001, **13**, 167-172

Prediction of Maximal Aerobic Power in Adolescents from Cycle Ergometry

Alan P. Jung, David C. Nieman, and Michael W. Kernodle

The purpose of this study was to validate an existing $\dot{V}O_{2max}$ prediction equation for a graded cycle ergometer test, using adolescents as subjects (14). Healthy, active males (n = 19) and females (n = 19), ages 13–18 years old, pedaled at a rate of 60 rpm until exhaustion, with resistance increasing 15 W every minute. Oxygen uptake, ventilation, and respiratory exchange ratio were measured continuously. A significant correlation was found between predicted and actual $\dot{V}O_{2max}$ for both male ($r = 0.90, p < .001$) and female ($r = 0.91, p < .001$) adolescents. For all subjects combined the correlation was $r = 0.96, p < .001$ with an SEE = 198 ml · min^{-1}. Mean differences between actual and predicted $\dot{V}O_{2max}$ values were 1.0 ± 0.7 ml · kg^{-1} · min^{-1} and 2.0 ± 0.7 ml · kg^{-1} · min^{-1} for the males and females, respectively (2.1% and 5.2% difference). The data indicate these cycle ergometry equations are valid for prediction of $\dot{V}O_{2max}$ in male and female adolescents.

Introduction

Prediction of $\dot{V}O_{2max}$ is necessary when measurement of expired gases is not possible; therefore, numerous equations have been developed to estimate oxygen consumption during submaximal and graded maximal protocols. Treadmill equations associated with the Bruce and Balke protocols are widely used and have been shown to provide reliable maximal data (5, 7). These equations are based on exercise duration, as work rate is difficult to assess while on a treadmill.

The American College of Sports Medicine (ACSM) has developed an equation to predict oxygen consumption using a cycle ergometer (1). This equation has been found to be accurate at submaximal levels (SEE = 79–156 ml · min^{-1}), but it is only valid during steady state exercise, so it cannot be used to predict $\dot{V}O_{2max}$ (12). The SEEs for submaximal prediction have ranged from 79 ml · min^{-1} to 231 ml · min^{-1} when considering several modifications of the equation (3, 10–12). Greiwe et al. (8) attempted to predict $\dot{V}O_{2max}$ with the ACSM equation, which resulted in an overprediction in each of two trials (SEE = 6.0 ml · kg^{-1} min^{-1} and 6.4 ml · kg^{-1} · min^{-1}). A second study using the the ACSM equation to predict $\dot{V}O_{2max}$

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resulted in SEEs of 8.2 ml · kg^{-1} · min^{-1} and 7.4 ml · kg^{-1} · min^{-1} for two different pedaling cadences (15).

Equations for graded maximal cycle ergometer tests are less common than prediction equations using submaximal workloads, and typically, final workload rather than duration is used to determine $\dot{V}O_{2max}$. Andersen (2) had subjects perform graded maximal cycle tests in which workload increased 35 W every 2 min. An equation was developed using maximum power output and was compared to the actual $\dot{V}O_{2max}$. The equation, which did not incorporate age or body mass, resulted in a high correlation ($r = 0.88$), but no SEEs were reported. An equation to determine $\dot{V}O_{2max}$ from a 5 km timed cycle ergometer ride has also been developed (6). Subjects in this study completed a 5 km ride as quickly as possible, with cycle resistance based on body mass. An equation, based on the logarithm of cycle time, was then compared to each subject's treadmill $\dot{V}O_{2max}$. This equation resulted in a correlation of $r = -.83$ and a 14% SEE. Astrand and Ryhming (4) developed a submaximal cycle protocol. The submaximal equation for predicting $\dot{V}O_{2max}$ is based on target heart rate and has a large prediction error.

Storer et al. (14) have developed a reliable and valid equation for predicting $\dot{V}O_{2max}$ from a graded cycle ergometer test. The validation study resulted in equations that produced SEEs of 212 ml · min^{-1} and 145 ml · min^{-1} for males and females, respectively, which are lower than those reported for the Bruce treadmill equation (7). A nomogram has also been published to simplify use of this equation (13).

The Storer et al. (14) equation was validated with adults as subjects (20–70 yr), but has yet to be tested on a younger population. Therefore, the purpose of this study was to test the validity of this prediction equation on adolescents using a graded cycle ergometer test.

Methods

Subjects included 20 (10 male, 10 female) elite teenage tennis players from the Van Der Meer World Class Tennis Training Center in Hilton Head, South Carolina, and 18 (9 male, 9 female) non-athlete, age-matched controls. The objective in choosing athletes and non-athletes was to ensure a wide range of maximal aerobic power measurements for validating the Storer et al. (14) equation in adolescents. Our objective was not to contrast athletes and non-athletes in this study.

Each subject performed a maximal graded cycle ergometer test using the protocol described by Storer et al. (14). All tests were performed on a mechanically braked Monark cycle ergometer (Monark-Cresent AB, Varberg Sweden). Following a 4-min warm-up at 0 watts, the workload was increased 15W (1/4 kp) every minute until the subject stopped pedaling or was unable to maintain the designated cadence. Pedal rate was maintained at a constant rate of 60 rpm through use of a metronome and verbal encouragement from the investigators. Oxygen uptake, ventilation, respiratory rate, and respiratory exchange ratio were measured continuously using the MedGraphics CPX metabolic system (MedGraphics Corporation, St. Paul, MN). This system measures respiratory gases breath-by-breath and has been shown to be a valid method of analyzing metabolic and respiratory function at rest and during exercise (Dr. Michael Berry, Wake Forest University, personal communication, 1997). Analyzers were calibrated using gases provided by the MedGraphics Corporation. The calibration gas contained 5% CO_2, 12% O_2, and balance N_2, and the reference gas contained 21% O_2 and balance N_2. The

standard specification of error for the
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Estimated $\dot{V}O_{2max}$ (ml · min^{-1}) v
equations (14):

Males $\dot{V}O_{2max}$ = (10.51 x W) + (6.3

Females $\dot{V}O_{2max}$ = (9.39 x W) + (7.

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Re

Subject characteristics and maximal da
in age from 13 to 18 years of age. Maxin
by all subjects and was based on meet
RER > 1.10, heart rate within 12 bpm
maintain pedal cadence despite urging

Table 1 Characteristics of Male and

	Ma (*N* =
Age (yr)	16.0 ±
Height (cm)	177 ±
Body mass (kg)	69.9 ±
Body mass index (kg · m^{-2})	22.3 ±
Body fat (%)	11.6 ±
HR_{max} (beats · min^{-1})	199 ±
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	
Measured	49.4 ±
Estimated	48.4 ±
VE_{max} (l · min^{-1})	122 ±
RR_{max} (breaths · min^{-1})	50.2 ±
RER_{max}	1.17 ±
$Workload_{max}$ (W)	245 ±

HR_{max} = maximal heart rate; $\dot{V}O_{2max}$ = max
ventilation rate; RR_{max} = maximal respiratory
ratio.

ınd 7.4 ml · kg^{-1} · min^{-1} for two different

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standard specification of error for the reference and calibration gas is ±0.10%. The metabolic system was calibrated prior to each test. Metabolic values were recorded every minute. Heart rate was measured continuously using chest monitors (Polar Electro Inc., Woodbury, NY). Body composition was estimated from seven skinfolds using the Jackson and Pollock (9) equations.

Estimated $\dot{V}O_{2max}$ (ml · min^{-1}) values were calculated using the following equations (14):

$$\text{Males } \dot{V}O_{2max} = (10.51 \times W) + (6.35 \times kg) - (10.49 \times age) + 519.3 \text{ ml} \cdot \text{min}^{-1}$$

$$\text{Females } \dot{V}O_{2max} = (9.39 \times W) + (7.7 \times kg) - (5.88 \times age) + 136.7 \text{ ml} \cdot \text{min}^{-1}$$

Pearson r correlations were used to determine any relationship between the measured and predicted $\dot{V}O_{2max}$ values for males, females, and all subjects combined. Paired sample *t*-tests were used to determine if there was a difference between estimated and predicted $\dot{V}O_{2max}$ values. Results are reported as mean ± SE.

Results

Subject characteristics and maximal data are displayed in Table 1. Subjects ranged in age from 13 to 18 years of age. Maximal effort during the cycle test was achieved by all subjects and was based on meeting two of three of the following criteria: RER > 1.10, heart rate within 12 bpm of age-predicted maximum, and failure to maintain pedal cadence despite urging by the testing staff.

Table 1 Characteristics of Male and Female Adolescents (mean ± SE)

	Males (N = 19)	Females (N = 19)
Age (yr)	16.0 ± 0.3	15.9 ± 0.3
Height (cm)	177 ± 1.5	165 ± 1.8
Body mass (kg)	69.9 ± 1.7	59.3 ± 2.1
Body mass index (kg · m^{-2})	22.3 ± 0.6	21.8 ± 0.5
Body fat (%)	11.6 ± 1.1	21.0 ± 1.2
HR_{max} (beats · min^{-1})	199 ± 2	192 ± 2
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})		
Measured	49.4 ± 1.3	39.6 ± 1.5
Estimated	48.4 ± 1.1	37.6 ± 1.3
VE_{max} (l · min^{-1})	122 ± 4	91.0 ± 4.0
RR_{max} (breaths · min^{-1})	50.2 ± 2.4	50.8 ± 1.8
RER_{max}	1.17 ± 0.01	1.22 ± 0.01
$Workload_{max}$ (W)	245 ± 7	182 ± 8

HR_{max} = maximal heart rate; $\dot{V}O_{2max}$ = maximal oxygen consumption; VE_{max} = maximal ventilation rate; RR_{max} = maximal respiratory rate; RER_{max} = maximal respiratory exchange ratio.

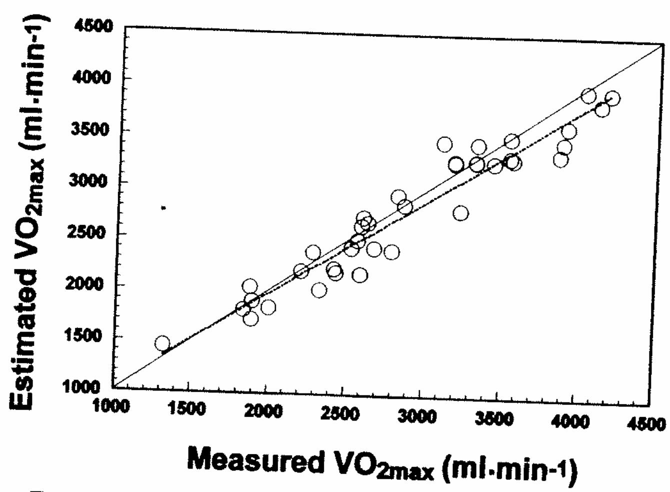


Figure 1 — For all subjects combined, the correlation between measured and estimated $\dot{V}O_{2max}$ was $r = 0.96, p < .001$, with an SEE = 3.0 ml · kg^{-1} · min^{-1}, or 198 ml · min^{-1}. The solid line is the line of identity. The dashed line in the line of best fit.

A significant correlation was found between the actual and predicted $\dot{V}O_{2max}$ values for both male ($r = 0.90, p < .001$) and female ($r = 0.91, p < .001$) adolescents. The corresponding SEE values were 3.0 ml · kg^{-1} · min^{-1} for each group, or 203 ml · min^{-1} and 182 ml · min^{-1} for males and females, respectively. For all subjects combined, the correlation was $r = 0.96, p < .001$, with an SEE = 3.0 ml · kg^{-1} · min^{-1}, or 198 ml · min^{-1}. Individual data points for actual and predicted $\dot{V}O_{2max}$ are displayed in Figure 1.

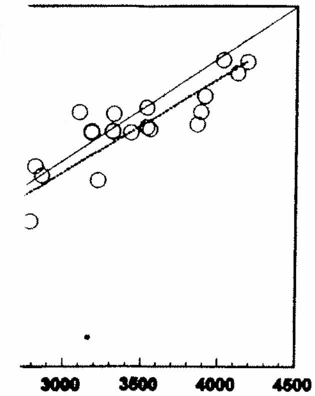
The mean difference between actual and predicted $\dot{V}O_{2max}$ values for males was 1.0 ± 0.7 ml · kg^{-1} · min^{-1} (49.4 ± 1.3 ml · kg^{-1} · min^{-1} vs. 48.4 ± 1.1 ml · kg^{-1} · min^{-1}), representing a 2.1% difference. The mean difference for females was 2.0 ± 0.7 ml · kg^{-1} · min^{-1} (39.6 ± 1.5 ml · kg^{-1} · min^{-1} vs. 37.6 ± 1.3 ml · kg^{-1} · min^{-1}), representing a 5.2% difference. A paired samples t-test revealed a significant difference between actual and predicted $\dot{V}O_{2max}$ values for females ($p = 0.01$), but not for the males.

When combining groups, a mean difference of 1.5 ± 0.5 ml · kg^{-1} · min^{-1}, or 98.6 ± 32.2 ml · min^{-1}, was found, resulting in a 3.4% difference. A paired samples t-test revealed a significant difference between actual and predicted values for the combined group ($p < .05$).

Discussion

$\dot{V}O_{2max}$ values are most accurate when expired gases are measured. However, in situations where metabolic equipment is not available and $\dot{V}O_{2max}$ values are needed, an equation that accurately predicts $\dot{V}O_{2max}$ is useful.

The purpose of this study was to validate two gender-dependent $\dot{V}O_{2max}$ prediction equations using a cycle ergometer, with adolescents as subjects. Storer et al. (14) developed one of the few available cycle ergometer equations for predicting $\dot{V}O_{2max}$. They reasoned that a graded cycle ergometer test, compared to a treadmill



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test, would more accurately predict $\dot{V}O_{2max}$ because it is based on maximum wattage rather than time to exhaustion. The prediction equations were a result of tests using 115 males and 116 females, ages 20–70 years old. When compared to measured $\dot{V}O_{2max}$, estimated $\dot{V}O_{2max}$ values from the prediction equation were highly correlated and had low SEEs for both males (r = 0.93, 212 ml · min^{-1}) and females (r = 0.94, 145 ml · min^{-1}). This study tested the validity of the equations on adolescent subjects.

Compared to the original study, our data with adolescents revealed similar correlations between measured and estimated $\dot{V}O_{2max}$ for both males (r = 0.90) and females (r = 0.91). SEEs of 208 ml · min^{-1} and 182 ml · min^{-1} for males and females, respectively, were also similar to those reported in the original study. The mean differences between measured and predicted $\dot{V}O_{2max}$ are low for both males (1.0 ± 0.7 ml · kg^{-1} · min^{-1}) and females (2.0 ± 0.7 ml · kg^{-1} · min^{-1}). Additionally, when combining males and females, our results showed the equations only slightly under-predicted $\dot{V}O_{2max}$ compared to measured (–98.6 ± 32.2 ml · min^{-1}). The Storer et al. (14) equation has been found to be valid and reliable in predicting $\dot{V}O_{2max}$ in adults. Our results are similar to those found with adults and suggest the equation may be valid in predicting $\dot{V}O_{2max}$ in adolescents as well. The equation was expected to be valid for adolescents due to the incorporation of age into the equation. In addition, adolescents are as capable of achieving a maximal effort as adults. As summarized in Table 1, all of our subjects met the criteria for maximal effort.

Paired sample t-tests revealed a significant difference between actual and predicted $\dot{V}O_{2max}$ values for the female group and for all subjects combined. However, the high correlations, low SEEs, and low mean differences reveal that the equation is capable of generating an estimated $\dot{V}O_{2max}$ value that is very close to the measured value. Additionally, the error values from this equation are as low as other reported values in predicting $\dot{V}O_{2max}$. Therefore, the finding of a significant difference should not outweigh the strength of the equation and its usefulness in accurately estimating aerobic power in adolescents. The difference was most likely due to a small but consistent underestimation by the equation, with minimal variability between measured and predicted $\dot{V}O_{2max}$.

To our knowledge, only one other published equation predicts $\dot{V}O_{2max}$ based on maximal power output. An equation was developed after testing 232 males and 303 females, age 15–28 years (2). Each subject was tested twice, 8 years apart, with all tests analyzed as separate cases. The equation is as follows: $\dot{V}O_{2max}$ = 0.16 + (0.0117 x W). Weight, gender, and age were not included in the equation because the authors determined these variables caused little variation in $\dot{V}O_{2max}$ prediction. Andersen (2) found a correlation of r = 0.88 between actual and predicted $\dot{V}O_{2max}$ values. Unfortunately, no SEE values were reported for this equation, so it is difficult to assess its true value. When maximum power output values from the present study were entered into the Andersen equation, a correlation of r = 0.94 with an SEE of 247 ml · min^{-1} resulted for all subjects combined. Additionally, $\dot{V}O_{2max}$ was under-predicted by –230 ± 46 ml · min^{-1}. These values indicate more error than those we found using the Storer et al. (14) equation.

The Storer et al. (14) equation resulted in lower SEEs, lower mean differences between measured and predicted values, and higher correlations than other published $\dot{V}O_{2max}$ prediction equation using cycle ergometry from either submaximal or maximal protocols (2, 8, 14, 15). The results from the present study support the use of the Storer et al. (14) prediction equation for estimating $\dot{V}O_{2max}$ in adolescents.

Conclusion

$\dot{V}O_{2max}$ data for adolescents are useful in assessing changes in aerobic power in response to exercise training in physical education and community sports programs. Metabolic equipment is typically not available for measurement of $\dot{V}O_{2max}$; therefore, an accurate prediction equation for adolescents is useful. The results from this study show that the Storer et al. (14) equations predict $\dot{V}O_{2max}$ in adolescents with a relatively small degree of error. Thus, we recommend the use of the Storer et al. (14) equations for estimating $\dot{V}O_{2max}$ in adolescents.

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The Prevalenc
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Constantin Bouziotas,
Yiannis Pananakakis, Va

The prevalence of 14 selected
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C. Bouziotas and R. Shiner are w
Wolverhampton, WV1-1DJ, England, UK
versity, Trikala, Greece and the School of
Wolverhampton, UK; Y. Pananakakis is w
Greece; V. Fotopoulou is at Parmenionos
the National Hospital of Katerini, Greece.