0195-9131/92/2402-0272$3.00/0
MEDICINE AND SCIENCE IN SPORTS AND EXERCISE

Vol. 24, No. 2
Printed in U.S.A.

TECHNICAL NOTE

The accuracy of the ACSM cycle ergometry equation

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ABSTRACT

LANG, P. B., R. W. LATIN, K. E. BERG, and M. B. MELLION. The accuracy of the ACSM cycle ergometry equation. *Med. Sci. Sports Exerc.*, Vol. 24, No. 2, pp. 272–276, 1992. The purpose of this study was to determine the accuracy of the American College of Sports Medicine's equation for estimating the oxygen cost of exercise performed on a cycle ergometer. Sixty healthy males, ages 19–39 yr old, performed a five stage (30, 60, 90, 120, and 150 W) submaximal cycle ergometer test while their oxygen uptake was measured. Results indicated the standard error of estimate for the predicted oxygen values ranged from 0.11 to 0.22 $l \cdot min^{-1}$, with correlations between the actual and predicted values ranging from r = 0.22 to r = 0.50. Total errors ranged from 0.23 to 0.31 $l \cdot min^{-1}$. The actual oxygen cost was underestimated from 0.16 to 0.29 $l \cdot min^{-1}$ ($P < 0.05$) by the equation at each workload. A revised equation was developed based upon the actual $\dot{V}O_2$-power relationship. The resulting slope was lower and the intercept higher when compared with the current ACSM equation. The slope and intercept of the revised equation are more consistent with values published in the literature. This equation appears as:

$$\dot{V}O_2\ (ml \cdot min^{-1}) = kgm \cdot min^{-1} \times 1.9\ ml \cdot min^{-1})$$
$$+ ((3.5\ ml \cdot kg^{-1} \cdot min^{-1} \times kg\ body\ weight) + 260\ ml \cdot min^{-1})$$

Predicted values from the revised equation were more accurate as reflected by slightly higher correlations, lower total errors, and lower mean differences from actual $\dot{V}O_2$ measurements than those from the current equation.

OXYGEN CONSUMPTION, EXERCISE, ERGOMETRY, CYCLING, PREDICTION OF $\dot{V}O_2$

Since the advent of scientific tests designed to measure oxygen consumption there have been attempts to develop an accurate method to estimate oxygen uptake during exercise (2,3,6). Many of these prediction methods are currently used and undergo periodic reevaluation. Among methods for estimating oxygen uptake are the American College of Sports Medicine's (ACSM) metabolic equations (2). These equations are commonly used for exercise prescriptions and fitness evaluations in many settings. The ACSM cycle ergometer equation uses pedaling frequency, distance of flywheel travel, applied resistance to the flywheel, and an estimation of resting metabolism to predict the oxygen cost of cycle exercise. A simplified version of the equation appears as:

$$\dot{V}O_2\ (ml \cdot min^{-1}) = (kgm \cdot min^{-1} \times 2\ ml \cdot kgm^{-1})$$
$$+ (3.5\ ml \cdot kg^{-1} \cdot min^{-1} \times kg\ body\ weight).$$

The factors and constants used in the metabolic equation represent components of the test subject and the ergometer. Although their inclusion in the equation represents scientific principles, there is little research addressing the accuracy of the ACSM equation as a predictor of the metabolic response during cycle ergometry. Therefore, a comparison of the actual and predicted cost is warranted to establish a level of accuracy of the equation.

METHODS

Subjects. The subjects were 60 healthy males 19–39 yr of age. All subjects were free from major cardiovascular risks, orthopedic and metabolic diseases, and disabilities. All were nonsmokers. None were trained cyclists. All were limited in current cycling to less than three times per week, 15 min per session and to never having cycled more than 50 miles$\cdot wk^{-1}$ for 4 consecutive wk. Descriptive data for the subjects may be seen in Table 1.

Pretest. Subjects were required to avoid eating food for 4 h prior to testing and to avoid heavy exertion or exercise 12 h prior to participation. After obtaining a description of the test procedure and signing a written

Submitted for publication November, 1989.
Accepted for publication July, 1991.

TABLE 1. Description of subjects (n = 60)

Variable	M	SD	Range
Age (yr)	27.2	5.3	19.0–39.0
Weight (kg)	78.2	11.3	53.8–118.8
Height (cm)	176.7	6.7	151.0–191.0

informed consent, each subject was weighed to the nearest 0.1 kg and their height measured to the nearest 0.5 cm using a stadiometer on a medical grade scale.

Cycle adjustment and power. A Model 850 Monark cycle ergometer without toeclips was used in this experiment. The cycle was calibrated once weekly using known reference weights. Approximately seven tests took place between each calibration. Minimal adjustment was needed at each calibration, suggesting a relatively constant and stable resistance was maintained during all testing procedures. A revolution counter was attached to the ergometer to count the rpm of the subject's pedal cranking. Seat height was adjusted to 109% of the subject's symphysis pubis height, as suggested by Nordeen-Snyder (10). Symphysis pubis height was measured from the ground-to-top edge height of a ruler placed between the thighs at crotch height, parallel to the ground. Seat height was measured from the axle of the foot pedal placed at bottom-dead-center in line with the seat tube to the top of the seat. In a small number of cases the subject experienced knee hyperextension while seated on the cycle with the pedal at bottom-dead-center after the initial and repeated measurement of the symphysis pubis height. To remedy this, the seat was lowered progressively until the knee was flexed 5–10 degrees. This appears within the guidelines recommended by Broker et al. (4), who suggested that seat heights varying between 105 and 110% of crotch height appear to have little effect on force application patterns. During the tests the subjects were seated in an upright position on the cycle.

Metabolic measurements. The subjects were then attached to a Sensormedics MMC Horizon Systems metabolic cart for collection of expired air. The metabolic cart was calibrated before each test according to the Sensormedics Operating Manual (12) by using a reference gas of known concentration, volume, and temperature. The subjects breathed through a low resistance breathing valve and wore a noseclip.

Test. Steady rate oxygen consumption at each stage was used to compare with the predicted value obtained from the ACSM equation. A steady rate occurred when the absolute difference in oxygen consumption in $ml \cdot min^{-1}$ between two successive minutes, after 3 min of a single stage (7), did not exceed 50 $ml \cdot min^{-1}$. The mean of those two minutes was used as the steady rate value.

After obtaining resting data for 5 min, the subjects began pedaling on the ergometer at 30 W for 5 min at 60 rpm. The subjects were asked to pedal at a constant rate (60 rpm) throughout all power outputs as dictated by an audible tempo produced by a metronome. As previously mentioned, the subject's pedaling rpm was measured with a crank revolution counter attached to the ergometer. The counted rpm was then used to calculate the actual power output for each subject at every stage of the test. After the 5-min warmup, the test began at 60 W and included additional stages of 90, 120, 150, and 180 W. After reaching a steady rate, the power was increased to the next stage. Succeeding stages progressed until the subject reached 85% of their predicted maximum heart rate, using the formula of 220 minus the subject's age or until the subject finished the 180 W stage. Heart rate was measured with a five-lead ECG. The warmup stage (30 W) was added to the analysis after finding that many subjects (n = 56) reached a steady rate in the 5 min allotted. Also, since steady rate $\dot{V}O_2$ above the lactate threshold (LT) is more slowly developed and most of the subjects were probably above LT at 180 W, this power load was eliminated from subsequest analyses (11).

Statistical analysis. The standard error of estimate ($SEE = S_y \sqrt{1 - r^2}$) and total error ($E = \sqrt{\Sigma(Y - Y')^2/N}$) were calculated to show the accuracy of the predicted oxygen cost values. Pearson correlation coefficients were used to show the relationship between the predicted and actual oxygen consumption and a correlated t-test was used to compare the predicted and actual-test group means. Regression analysis was used to develop prediction equations from actual $\dot{V}O_2$ values. The probability of making a Type I error was set at $P = 0.05$.

RESULTS

The results of this study show that there was a significant difference ($P < 0.05$) between the mean actual ($A\dot{V}O_2$) and predicted ($P\dot{V}O_2$) oxygen cost of cycling at each power output. These differences ranged from 0.19 to 0.29 $l \cdot min^{-1}$. Figure 1 contains mean values for $A\dot{V}O_2$ and $P\dot{V}O_2$ at each power output, while Figure 2 contains a scattergram and identity line for all $A\dot{V}O_2$ and $P\dot{V}O_2$ data pairs. Pearson correlation coefficients between the actual and predicted oxygen values ranged from r = 0.22 to r = 0.50, with all but one correlation being significant ($P < 0.05$). Standard error of estimate values were also computed and ranged from 0.11 to 0.22 $l \cdot min^{-1}$, while total errors ranged from 0.23 to 0.31 $l \cdot min^{-1}$. These results can be seen in Table 2.

DISCUSSION

One typical measure of the accuracy of a predicted score and thus the equation from which it is derived is the SEE. The SEE may be used to establish a confidence

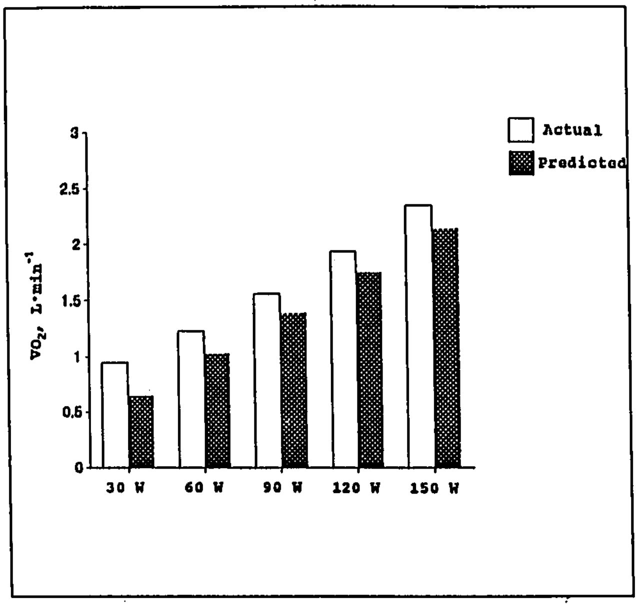

Figure 1—Histogram of mean values for actual and predicted $\dot{V}O_2$ at five power loads. Actual $\dot{V}O_2$ was significantly underestimated (P < 0.05) by the current ACSM equation at each load.

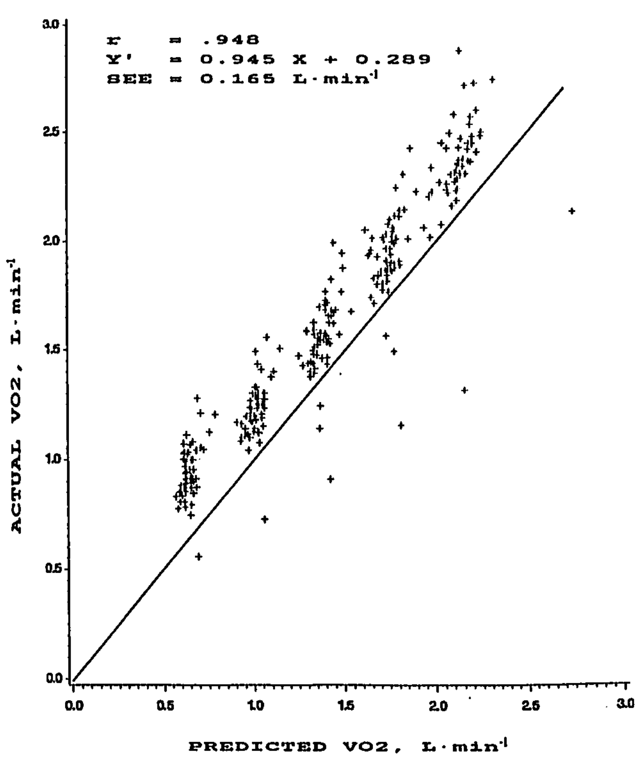

Figure 2—Scattergram and line of identity for actual and predicted $\dot{V}O_2$ at five power loads (n = 287). Predicted $\dot{V}O_2$ values were derived from the current ACSM equation.

interval for the actual score around a predicted value, and therefore the smaller the SEE, the more accurate the prediction. The SEE values for the predicted oxygen costs in this study ranged from 0.11 to 0.22 $l \cdot min^{-1}$. Using the mean body weight of 78.2 kg for our subjects, these errors relative to body weight would be from 1.4 to 2.8 $ml \cdot kg^{-1} \cdot min^{-1}$. This would translate the errors to be less than one MET.

The total error (E) is another statistic that may be used to indicate the accuracy of a prediction equation. This statistic takes into account the total deviations of the predicted values from the actual scores. Therefore, E indicates not only the dispersion of scores around a regression line (SEE) but any other systematic errors or deviations. Like the SEE, a smaller E associated with an equation or predicted value is judged to be more accurate. The Es were somewhat larger than the SEEs ranging from 0.23 to 0.31 $l \cdot min^{-1}$.

When evaluating the magnitude of the SEEs of this metabolic equation, it is helpful to compare the errors with other equations predicting the oxygen cost of exercise. Montoye et al. (8) validated the ACSM equation for estimating $\dot{V}O_2$ in level and grade walking. In the age group similar to the present study's (male, age 25–29, n = 35) the SEE was 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$ for level walking and ranged from 1.3 to 2.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for grade walking. Morrow et al. (9) tested the ACSM running equation on well trained athletes at altitude. They found that the SEEs for men and women were 3.7 and 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, and the equation overestimated the $\dot{V}O_2$ for males (M = 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$) and females (M = 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$). The ACSM arm ergometry equation was examined by Allison et al. (1) among healthy males. The $\dot{V}O_2$ was underpredicted by the equation by 173, 24, and 249 $ml \cdot min^{-1}$ for the 25, 50, and 100 W power outputs, respectively. At 75 W, the values were identical. In light of these studies, it would seem that the SEE values of the present study are similar to those previously reported.

The correlation coefficient may also be examined as an index of validity. The correlations between $A\dot{V}O_2$ and $P\dot{V}O_2$ ranged from low to moderate (r = 0.22 to r = 0.50) in terms of strength. However, this is probably a function of the limited range and small variability of the actual and predicted values at each power output. Therefore, this should be considered when judging the magnitude of these statistics as a measure of the equation's correctness.

Mean differences are less important than the SEE and E from an equation accuracy standpoint. However, it is interesting to examine these differences for each power output. Underestimations of $A\dot{V}O_2$ were observed at each level. The mean differences between $A\dot{V}O_2$ and $P\dot{V}O_2$ ranged from 0.19 to 0.29 $l \cdot min^{-1}$, and all were statistically significant ($P < 0.05$).

Since the mean $P\dot{V}O_2$ was similar in the amount of underestimation at each power output, it was of interest to determine if the accuracy of the current ACSM equation could be improved. To that end a regression analysis was performed using all of the $A\dot{V}O_2$s (Y) and all of the power outputs (X). The following equation

TABLE 2. Comparison of the actual and predicted oxygen cost ($l \cdot min^{-1}$) at selected cycling power outputs

	Power (W)		Actual		Predicted						
n	M	SD	M	SD	M	SD	Diff	SEE	E	*r*	*t*
					Current ACSM equation						
56	30.9	1.1	0.94	0.12	0.65	0.04	−0.29	0.11	0.31	.44*	16.90*
60	61.9	2.4	1.23	0.14	1.03	0.11	−0.20	0.12	0.24	.50*	9.18*
60	92.7	2.9	1.55	0.17	1.39	0.05	−0.16	0.15	0.23	.46*	7.47*
59	122.5	5.1	1.93	0.18	1.74	0.07	−0.19	0.17	0.25	.32*	7.42*
52	153.7	6.2	2.35	0.23	2.14	0.12	−0.21	0.22	0.31	.22	5.92*
					Revised equation						
56	30.9	1.1	0.94	0.12	0.89	0.04	−0.05	0.10	0.12	.47*	3.66*
60	61.9	2.4	1.23	0.14	1.23	0.05	0.0	0.12	0.12	.54*	0.61
60	92.7	2.9	1.55	0.17	1.59	0.04	0.04	0.15	0.16	.43*	1.78
59	122.5	5.1	1.93	0.18	1.93	0.07	0.0	0.17	0.17	.32*	−0.05
52	153.7	6.2	2.35	0.23	2.29	0.08	−0.06	0.20	0.21	.46*	2.00

* $P < 0.05$.

was the result of that analysis:

$$VO_2\ (ml \cdot min^{-1}) = (kgm \cdot min^{-1} \times 1.9\ ml \cdot kgm^{-1}) + 535\ ml \cdot min^{-1}$$

After factoring in an estimation of resting metabolism per kg of body weight the additional $\dot{V}O_2$ was approximately 260 $ml \cdot min^{-1}$, which resulted in the final equation:

$$VO_2\ (ml \cdot min^{-1}) = (kgm \cdot min^{-1} \times 1.9\ ml \cdot kgm^{-1}) + ((3.5\ ml \cdot kg^{-1} \cdot min^{-1} \times kg\ body\ weight) + 260\ ml \cdot min^{-1}).$$

This equation was then applied to all of the power outputs thereby developing new $P\dot{V}O_2$ values. These data were then analyzed using the same statistical treatments mentioned previously. The results of these procedures may be seen in Table 2.

The correlations associated with the revised equation ranged from r = 0.32 to r = 0.54 ($P < 0.05$). Three of these values were slightly higher, one lower, and one no different than those related to the current ACSM equation, making the revised equation somewhat more accurate from this point of view. Since there were only small changes in respect to the correlation coefficients, the SEEs of the revised equation were similar to that of the current ACSM equation. The most noticeable improvement in prediction accuracy is observed in the Es of the revised equation, which ranged from 0.12 to 0.21 $l \cdot min^{-1}$. The E at every power output was lower for the revised equation with these reductions ranging from 0.08 to 0.19 $l \cdot min^{-1}$, making the Es almost identical to the SEEs. This lowering was due to the removal of any systematic error. Finally, at four of the five power outputs, there was no significant difference ($P < 0.05$) between the mean values of $A\dot{V}O_2$ and $P\dot{V}O_2$. These differences ranged from − 0.05 to 0.04 $l \cdot min^{-1}$. An inspection of the mean differences for both equations reveals that the revised equation's accuracy was substantially better from this standpoint.

The distinctions between the current ACSM equation and the revised one are in both the slope and intercept of the $\dot{V}O_2$-power relationship. The slope of the current ACSM equation is based on a 1.8 $ml \cdot kgm^{-1}$ with a supplemental 0.2 $ml \cdot kgm^{-1}$ to account for the frictional work in the ergometer (2). The revised equation's slope reflects a 1.9 $ml \cdot kgm^{-1}$ $\dot{V}O_2$-power relationship. This slope could be a slight overestimation of the true $\dot{V}O_2$-power relationship. Further regression analyses of the three lowest and four lowest $\dot{V}O_2$-power relationships resulted in slopes of 1.7 and 1.8 $ml \cdot kgm^{-1}$, respectively. This small increase in the size and difference of the slope could be explained by the continuous nature of the testing protocol. A slowly developing $\dot{V}O_2$ at each power output, particularly as intensity approached LT, could have had an additive effect at each stage. This ultimately resulted in the 1.9 $ml \cdot kgm^{-1}$ slope for all power outputs. The 1.7, 1.8, and 1.9 $ml \cdot kgm^{-1}$ slopes are similar to others that have been previously reported (11,13). Furthermore, they are all lower than the 2.0 $ml \cdot kgm^{-1}$ slope appearing in the current ACSM equation. The differences in estimated $\dot{V}O_2$ among all of the different regressions including the current ACSM equation, range from 1.2 to 5%. Also, it would be important to consider that the O_2 cost of exercise may be underestimated by the current or revised equation for exercise where a slowly developing $\dot{V}O_2$ may be expected (i.e., short-term exercise above LT).

The slope does not appear to be the most significant source of error in the current ACSM equation. This is supported by the small differences stated previously and the results of a *t*-test for beta weights (1.9 vs 2.0 $ml \cdot kgm^{-1}$), which was not significant ($P > 0.05$). The larger source of error seems to be the equation's intercept, which is based only on an estimate of the resting metabolism of the subject. The revised equation, however, is based on a resting metabolism estimation and an additional 260 ml of O_2. The O_2 cost of unloaded cycling (power = 0) could account for the extra 260 ml. The mathematically derived 260 ml in the revised equation is almost identical to the 258 ml O_2 cost of unloaded cycling at 60 rpm reported by Whipp and Wasserman (13). Gaesser and Brooks (5) reported zero load cycling plus resting metabolism intercepts of 0.448 and 0.584 $l \cdot min^{-1}$ for pedaling 60 and 80 rpm, respectively. These values are similar to the 535 ml intercept of the revised equation. It would appear that this factor was not considered in the construct of the current ACSM equation or that the additional 0.2 $ml \cdot kgm^{-1}$ cannot adequately compensate for this component of cycle ergometry.

The Monark 850 ergometer used in this investigation is friction braked by a fabric belt around the flywheel. Results from previous studies (5,11,13,14) indicate similar slopes, intercepts, and/or O_2 costs for power outputs using both friction and electrically braked types of ergometers. Wilmore et al. (14) reported similar $\dot{V}O_2$ values for two friction types (belt and hydraulic) and an electrically braked ergometer across several power outputs. A fourth ergometer, friction braked by a disc/spring apparatus, produced significantly different values from the other types. It would appear that the results of this study may be generalized to most types of ergometers.

The revised equation contains a slope reflecting an actual $\dot{V}O_2$-power relationship. It also has an intercept based on an estimation of resting metabolism plus an additional 260 ml, which may reflect the O_2 cost of unloaded cycling. The slope and intercept are consistent with previously reported values. The revised equation is more exact at each power output, particularly in respect to each E and mean difference. It would appear that the revised equation provides a more accurate depiction of the true cycle ergometry $\dot{V}O_2$-power relationship. Therefore, a more precise prediction of the $\dot{V}O_2$ of cycle ergometry power outputs for men between the ages of 19 and 39, will result from its use. However, the accuracy of this prediction holds only for power outputs that are below LT, where the slowly developing phase of $\dot{V}O_2$ is absent or negligible.

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