Accuracy of prediction equations to estimate submaximal $\dot{V}O_2$ during cycle ergometry: The HERITAGE Family Study

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ABSTRACT

STANFORTH, P. R., M. D. RUTHVEN, J. GAGNON, C. BOUCHARD, A. S. LEON, D. C. RAO, J. S. SKINNER, and J. H. WILMORE. Accuracy of prediction equations to estimate submaximal $\dot{V}O_2$ during cycle ergometry: The HERITAGE Family Study. *Med. Sci. Sports Exerc.*, Vol. 31, No. 1, pp. 183–188, 1999. It was hypothesized that more accurate equations for estimating submaximal $\dot{V}O_2$ during cycle ergometry could be developed if more independent variables were used in the equation. **Purpose:** The purposes of this study were: (1) to develop new equations for estimating submaximal $\dot{V}O_2$ during cycle ergometry; and (2) to examine the accuracy of the newly developed equations and those of the American College of Sports Medicine (1995), Berry et al. (1993), Lang et al. (1992), Latin and Berg (1994), and Londeree et al. (1997). **Methods:** Subjects (715 men and women, ages 16–65 yr, from the HERITAGE Family Study) completed a maximal cycle ergometry test, two submaximal trials at 50 W and 60% of $\dot{V}O_{2max}$, hydrostatic weighing, and stature and body mass measures before and after 20 wk of cycle ergometry training. Regression analysis generated prediction equations using pretraining data from the 60% trials. **Results:** No equation with more independent variables was better than an equation that used only power output. This equation, HERITAGE-1, with only power output was cross-validated using the "jackknife" technique. Paired *t*-tests, mean differences, SEEs, and Es were used to compare the $\dot{V}O_2$ estimated by HERITAGE-1 and those of previously published equations with the measured $\dot{V}O_2$ at 60% of $\dot{V}O_{2max}$. **Conclusions:** HERITAGE-1 was slightly better than the equations of ACSM, Lang et al., and Latin and Berg using pretraining data but was not better when using post-training data. All four of these equations were superior to the equations of Berry et al. and Londeree et al. **Key Words:** OXYGEN UPTAKE, ENERGY EXPENDITURE (EE), ESTIMATING $\dot{V}O_2$

Estimating energy expenditure (EE) during exercise is a fundamental aspect of exercise testing and prescription (2). These estimates are used to determine the desired power output for optimal benefits during exercise training, to estimate the number of calories expended during exercise at a specific power output, and to estimate $\dot{V}O_{2max}$ from physiological responses (e.g., heart rate (HR)) at a given rate of work. Therefore, the American College of Sports Medicine has published equations for estimating oxygen uptake during walking, running, arm ergometry, leg (cycle) ergometry, and stepping (2). ACSM states that the intersubject variability in measured $\dot{V}O_2$ may have a SEE as high as 7% and that the variability when using prediction equations will be even greater.

Recent studies have focused on determining the accuracy of the ACSM equation for cycle ergometry (3,13–15). One should note that the ACSM equation was designed for power outputs between 50 and 200 W (2), not for power outputs less than 50 W. In general, these studies have found the ACSM equation to underestimate $\dot{V}O_2$ by 30% to 58% at power outputs from unloaded cycling to 30 W and from 0% to 16% at power outputs from 30 to 150 W. Consequently, these studies and others (5,17) have attempted to generate new equations to estimate more accurately submaximal $\dot{V}O_2$ during cycle ergometry.

Lang et al. (13) developed and Latin et al. (15) then validated an equation for estimating $\dot{V}O_2$ during cycle ergometry in men that appears to be more accurate than the ACSM equation. Latin and Berg (14) developed and cross-validated an equation for women, also finding it to be more accurate than the ACSM equation. Anderson and Wadden (3) have compared the Lang et al. (13) equation with the ACSM equation using obese women of varying ages and found it more accurate than the ACSM equation during cycle ergometry even though the Lang et al. (13) equation was developed for men.

Studies have found that $\dot{V}O_2$ during cycle ergometry is affected by both body mass (1,8,10) and pedal rate (6,9,12,19,22,24). The equations of ACSM (2), Lang et al. (13), and Latin and Berg (14), however, do not account for

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TABLE 1. Equations for predicting $\dot{V}O_2$ during cycle ergometry.

Author	R	SEE (mL·min^{-1})	Equation
ACSM (2)			$\dot{V}O_2$ (mL·min^{-1}) = (kgm·min^{-1} × 2.0 mL·min^{-1}) + (3.5 mL·kg^{-1}·min^{-1} × BM)
Berry et al. (5)	0.95@25–100 W	120@15–100 W	$\dot{V}O_2$ (mL·min^{-1}) = (10.9 × W) + (8.2 × RPM) + (8.3 × BM) − 559.6 mL·min^{-1}
Lang et al. (13)	0.54@62 W 0.32@123 W	120@62 W 170@123 W	$\dot{V}O_2$ (mL·min^{-1}) = (kgm·min^{-1} × 1.9 mL·min^{-1}) + (3.5 mL·kg^{-1}·min^{-1} × BM) + 260 mL·min^{-1}
Latin and Berg (14)	0.67@59 W 0.35@119 W	80@59 W 144@119 W	$\dot{V}O_2$ = (kgm·min^{-1} × 1.6 mL·min^{-1}) + (3.5 mL·kg^{-1}·min^{-1} × BM) + 205 mL·min^{-1}
Londeree et al. (17)	0.998@0–200 W	106@0–200 W	$\dot{V}O_2$ = (0.42 × W$^{1.2}$) + (0.00061 × RPM^3) + (6.35 × BM) + (0.1136 × RPM50 × W) − (0.10144 × RPM90 × W) − (52 × Sex)*
HERITAGE-1	0.938@20–210 W	145@20–210 W	$\dot{V}O_2$ = (11.33 × W) + 452 mL·min^{-1}

BM, Body mass in kg.

* Note: Where RPM50: 50 rpm = 1, and RPM90: 90 rpm = 1, else = 0. Sex: Male = 0, Female = 1.

References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 5. Berry, M. J., J. A. Storsteen, and C. M. Woodard. Effects of body mass on exercise efficiency and $\dot{V}O_2$ during steady-state cycling. *Med. Sci. Sports Exerc.* 25:1031–1037, 1993; 13. 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.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994; 17. Londeree, B. R., J. Moffitt-Gerstenberger, J. A. Padfield, and D. Lottmann. Oxygen consumption of cycle ergometry is nonlinearly related to power output and pedal rate. *Med. Sci. Sports Exerc.* 29:775–780, 1997.

differences in pedaling rate or in body mass, except in the estimation of the resting metabolic rate (RMR). In a study using 50 women with a wide range of body mass and two different pedaling rates, Berry et al. (5) developed a prediction equation for cycle ergometry $\dot{V}O_2$ using a combination of body mass, power output, and pedal frequency. Londeree et al. (17) in a study with 20 males and 20 females developed a nonlinear equation using body mass, power output, pedal rate, and gender.

The HERITAGE Family Study (7) is a multicenter research study involving 745 men and women (white and black), with wide ranges of age, body mass, relative body fat, and maximal oxygen uptake. Subjects were exercise tested, trained for 20 wk, and then retested using cycle ergometers. The exercise testing included steady-state rides at both 50 W and 60% of $\dot{V}O_{2max}$. This makes the HERITAGE Family study data base ideal for investigating the accuracy of estimating submaximal $\dot{V}O_2$ during cycle ergometry. Therefore, the purposes of the present study were: 1) to develop new equations for estimating submaximal $\dot{V}O_2$ during cycle ergometry using the HERITAGE Family study data set and 2) to examine the accuracy of the equations of the ACSM (2), Berry et al. (5), Lang et al. (13), Latin and Berg (14) and Londeree et al. (17) (see Table 1) along with the newly developed equations for estimating submaximal $\dot{V}O_2$ during cycle ergometry using the HERITAGE Family study data set.

METHODS

Subjects. The HERITAGE subject population is composed of black and white families, including the natural father and mother and their offspring 16 yr of age and older. Subjects were recruited by each of four clinical centers located at Arizona State University (relocated to Indiana University), Laval University, the University of Minnesota, and The University of Texas at Austin. Subjects for the current investigation are the 715 subjects (174 black females, 235 white females, 85 black males and 221 white males) with complete pre- and post-training exercise test data. Subject characteristics are presented in Table 2. The study protocol had been previously approved by each clinical center's Institutional Review Board, and informed consent was obtained from each subject. For further information on the HERITAGE Family Study, see Bouchard et al. (7).

Experimental design. Each subject completed three exercise tests conducted on separate days: a maximal exercise test (Max), a submaximal exercise test (Sub$_{max}$) and a submaximal-to-maximal exercise test (Sub$_{max}$-to-Max) which combined the protocols of the previous Sub$_{max}$ and Max tests. All exercise tests were conducted on a cycle ergometer (SensorMedics Ergo-Metrics 800S, Yorba Linda, CA). The Max test started at 40 or 50 W for 3 min, and the power output was increased by 20 or 25 W every 2 min thereafter to the point of exhaustion. Using the results of the initial maximal test, subjects performed the Sub$_{max}$ exercise test at 50 W and 60% of their initial $\dot{V}O_{2max}$. The Sub$_{max}$-to-Max exercise test was performed at 50W and 60% of initial $\dot{V}O_{2max}$ and progressed in graded increments to a maximal level of exertion.

Subjects then began a 20-wk exercise program. They exercised on a stationary cycle ergometer 3 d·wk^{-1} progressing from 30 min per workout at a HR corresponding to 55% of their initial $\dot{V}O_{2max}$ to 50 min per workout at a HR corresponding to 75% of their initial $\dot{V}O_{2max}$. At the conclusion of training, the subjects repeated the pretraining exercise testing procedures. The submaximal exercise testing was conducted at 50 W and 60% of the post $\dot{V}O_{2max}$.

Procedures. During the Sub$_{max}$ and Sub$_{max}$-to-Max exercise tests, subjects first exercised at the lower power output (50 W or 60%). They cycled until steady state was achieved and a cardiac output (CO) rebreathing procedure was then performed. The subjects continued to cycle until

TABLE 2. Physical characteristics of the subjects.

Variable	All Subjects (*N* = 715) Mean ± SD	Females (*N* = 409) Mean ± SD	Males (*N* = 306) Mean ± SD
Age (yr)	34.5 ± 13.6	34.1 ± 13.0	35.1 ± 14.4
Height (cm)	169.2 ± 9.4	167.5 ± 9.2	171.5 ± 9.2
Body mass (kg)	76.1 ± 17.2	75.2 ± 17.1	77.2 ± 17.3
Fat (%)	27.8 ± 10.6	29.2 ± 10.8	26.1 ± 10.0
Fat-free mass (kg)	53.6 ± 11.0	51.8 ± 10.3	56.0 ± 11.3
Fat mass (kg)	20.6 ± 4.2	21.4 ± 4.3	19.8 ± 4.0
BMI	26.5 ± 5.4	26.8 ± 5.7	26.1 ± 5.0

steady state was achieved again and a second CO rebreathing procedure was performed. There was then a 4-min period of seated rest before the procedure was repeated at the higher power output (50 W or 60%). The four steady-state $\dot{V}O_2$ measurements for each power output (two from the Sub_{max} and two from the Sub_{max}-to-Max exercise tests) were averaged to produce a single $\dot{V}O_2$ measurement for each subject at each power output. Thus, there was one $\dot{V}O_2$ value at 50 W and one value at 60% for each subject. The reproducibility of the four $\dot{V}O_2$ measures was excellent with coefficients of variation of 4.7% at 50 W and 3.6% at 60% and intraclass correlations for repeated measurements of 0.85 at 50 W and 0.99 at 60% (27).

For all exercise tests, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, and RER were determined every 20 s and reported as a rolling average of the three most recent 20-s values using a SensorMedics 2900 metabolic measurement cart (MMC). Pretest calibration and post-test verification of calibration were conducted on the MMC before and after each exercise test. Gas analyzers were calibrated using standard medical grade calibration gases. The volume flow probe was calibrated using a 3.0-L syringe. Subjects were instructed to cycle at about 75 rpm. Subjects and test technicians monitored this by watching the LED output on the control panel on the front of the cycle ergometer. The cycle ergometer was calibrated daily with a manual calibration at 1.5 kg, and verification of this calibration was then conducted at 0.5, 1.0, 2.0, 2.5, 3.0, and 3.5 kg.

Stature and body mass were measured in duplicate to the nearest 0.1 cm and 0.1 kg, respectively, using a stadiometer and balance beam scale. A third measurement was taken if the first two measurements differed by more than 0.5 cm for stature and 200 g for mass. Body mass index (BMI) was then calculated as body mass divided by stature in meters squared. Hydrostatic weighing was used to assess body density according to the method of Behnke and Wilmore (4), and a load cell interfaced with a computer was used to obtain the underwater measurement of body mass. At each of the four clinical centers, 10 underwater weighing trials were obtained and the three highest values were averaged. Residual lung volume was assessed out of water in a seated position using the oxygen-dilution principle, as described by Wilmore (26) and modified by Wilmore et al. (28), at the Indiana, Minnesota, and Texas Clinical Centers, and the helium-dilution technique (18,20) at the Quebec Clinical Center. A minimum of two trials were obtained, and a third trial was taken if the first two differed by more than 150 mL. An average of the first two trials, or the two closest trials, was used. Relative body fat was estimated from body density using the equations of Siri (25) for white men, Lohman (16) for white women, Schutte et al. (23) for black men, and Ortiz et al. (21) for black women. (Only 365 women and 283 men were able to complete the hydrostatic weighing. Therefore, any statistics involving %fat, fat mass, or fat-free mass are based this number of subjects.)

Statistical analysis. Regression analysis was used to generate new prediction equations using pretraining exercise test data from the 60% of $\dot{V}O_{2max}$ trials. Three models were used. HERITAGE-1 used power output as the only independent variable. HERITAGE-2 used power output plus demographics (age, race, and gender). HERITAGE-3 used power output, demographics, and physical characteristics (body mass, fat-free mass, %fat, height, and BMI). Model comparisons were then made using an *F* test on the differences in R^2 between the restricted model (HERITAGE-1) and the full models (HERITAGE-2 and HERITAGE-3.) If there was no significant difference between the restricted model and the full models, then the restricted model would be the prediction equation used.

The new prediction equation was then cross-validated using the "jackknife" estimate of bias in a sample, which involves sequentially deleting cases and the statistics of interest without that particular case (11). In this study, given that there were 715 participants, the jackknife estimates involved performing 715 regressions with each participant sequentially deleted and then averaging across the results of all 715 regressions.

The new prediction equation and the previously developed equations (2,5,13,14,17) were then compared with the measured $\dot{V}O_2$ at 60% of $\dot{V}O_{2max}$ using a paired *t*-test and correlation coefficient. The SEE and total error (E) were calculated to show the accuracy of the estimated $\dot{V}O_2$ values. E is equal to

$$\sqrt{\Sigma(Y - Y')^2/N}$$

where Y equals the measured value and Y′ equals the estimated value. These comparisons were conducted separately on both the pre- and post-training data. All statistics were computed using SAS 6.12.

RESULTS

Regression equations HERITAGE-1, 2, and 3 were developed and these equations had R values of 0.938, 0.939, and 0.947, respectively. An *F* test on the differences in R^2 between HERITAGE-1 and 2 showed that they were not significantly different [*F* (3,711) = − 0.619, *P* = 0.397)]. An *F* test on the differences in R^2 between HERITAGE-1 and 3 showed that they were not significantly different (*F* (7,707)) = − 2.128, *P* = 0.961). Therefore, only HERITAGE-1 was evaluated further and the equation for HERITAGE-1 is given in Table 1. This equation had an SEE of 145 mL·min^{-1}. The "jackknife" method was then used for cross-validation. The observed coefficient for power output was 11.33, and the jackknife mean was 11.33 with an estimated bias of only 0.001.

The comparison of the measured pretraining submaximal $\dot{V}O_2$ values and the values generated from the prediction equations during cycle ergometry at 60% of $\dot{V}O_{2max}$ are presented in Table 3. The mean measured $\dot{V}O_2$ ± SD was 1423 ± 438 mL·min^{-1}. Lang et al. (13) and Berry et al. (5) significantly ($P < 0.001$) overestimated, while the ACSM (2), Latin and Berg (14) and Londeree et al. (17) significantly underestimated ($P < 0.001$) the measured $\dot{V}O_2$. The equations of Berry et al. (5) and Londeree et al. (17) had

TABLE 3. Comparison of measured and predicted $\dot{V}O_2$ (mL·min^{-1}) during cycle ergometry at 60% of $\dot{V}O_{2max}$ (pre-training).

Equation	$\dot{V}O_2$	SD	Diff	SEE	E	*t*	*P*	r
ACSM (2)	1311	446	−112	155	193	19.0	<0.001	0.94
Berry et al. (5)	1620	416	197	201	281	−26.3	<0.001	0.89
Lang et al. (13)	1519	424	96	156	182	−16.6	<0.001	0.94
Latin & Berg (14)	1307	358	−117	160	202	18.7	<0.001	0.93
Londeree et al. (17)	1262	295	161	202	273	19.5	<0.001	0.89

Diff = measured − estimated; E = total error; and r = correlation coefficient.

References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 5. Berry, M. J., J. A. Storsteen, and C. M. Woodard. Effects of body mass on exercise efficiency and $\dot{V}O_2$ during steady-state cycling. *Med. Sci. Sports Exerc.* 25:1031–1037, 1993; 13. 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.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994; 17. Londeree, B. R., J. Moffitt-Gerstenberger, J. A. Padfield, and D. Lottmann. Oxygen consumption of cycle ergometry is nonlinearly related to power output and pedal rate. *Med. Sci. Sports Exerc.* 29:775–780, 1997.

TABLE 4. Comparison of measured and predicted $\dot{V}O_2$ during cycle ergometry at 60% of $\dot{V}O_{2max}$ (post-training).

Equation	$\dot{V}O_2$ mL·min mL·kg^{-1}·min^{-1}	SD mL·min mL·kg^{-1}·min^{-1}	Diff mL·min mL·kg^{-1}·min^{-1}	SEE mL·min mL·kg^{-1}·min^{-1}	E mL·min mL·kg^{-1}·min^{-1}	*t*	*P*	r
ACSM (2)	1611 21.3	511 6.8	−10 −0.1	145 1.9	153 2.0	1.82	=0.07	0.95
Berry et al. (5)	1887 25.0	473 6.3	266 0.4	181 2.4	322 4.3	−38.9	<0.001	0.93
Lang et al. (13)	1804 23.9	486 6.4	183 2.4	146 1.9	234 3.1	−33.0	<0.001	0.95
Latin & Berg (14)	1547 20.5	410 5.4	−74 −1.0	148 2.0	173 2.3	12.8	<0.001	0.95
Londeree et al. (17)	1452 19.2	349 4.6	−169 −2.2	188 2.5	270 3.6	21.5	<0.001	0.92
HERITAGE-1	1702 22.5	472 6.2	80 1.1	146 1.9	167 2.2	−14.8	<0.001	0.95

Diff, measured − estimated; E, total error; r, correlation coefficient.

References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 5. Berry, M. J., J. A. Storsteen, and C. M. Woodard. Effects of body mass on exercise efficiency and $\dot{V}O_2$ during steady-state cycling. *Med. Sci. Sports Exerc.* 25:1031–1037, 1993; 13. 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.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994; 17. Londeree, B. R., J. Moffitt-Gerstenberger, J. A. Padfield, and D. Lottmann. Oxygen consumption of cycle ergometry is nonlinearly related to power output and pedal rate. *Med. Sci. Sports Exerc.* 29:775–780, 1997.

lower correlations and higher mean differences, SEEs, and Es than all the other equations.

The comparison of the measured post-training submaximal $\dot{V}O_2$ values and the values generated from the prediction equations during cycle ergometry at 60% of $\dot{V}O_{2max}$ is presented in Table 4. The mean measured $\dot{V}O_2 \pm$ SD was 1622 ± 484 mL·min^{-1}. The ACSM equation (2) ($P = 0.07$) was the only equation that generated values that were not significantly different from the measured values and it had the lowest mean difference, SEE, and E.

The percentage of estimated values within 50, 100, 150, and 200 mL of the measured values at 60% for all of the equations are presented in Tables 5 and 6 for pre- and post-training values. More estimated values were within 50, 100, 150, and 200 mL of the actual values pretraining for all the HERITAGE-1 equation than for any of the previously published equations. At post-training, however, ACSM (2) had the highest percentage of values within 50, 100, 150, and 200 mL.

DISCUSSION

In this study we attempted to develop equations that would improve the estimation of submaximal $\dot{V}O_2$ during cycle ergometry. In the HERITAGE Family Study, we have noticed a greater variability in submaximal $\dot{V}O_2$ during cycle ergometry than had been anticipated, i.e., at 50 W, submaximal $\dot{V}O_2$ ranged from 794 to 1482 mL· min^{-1}, with a mean of 1035 mL·min^{-1}, and a SD of 126 mL·min^{-1}. A large variability was seen at all power outputs. We hypothesized that we could account for more of this variability in the development of a better prediction equation by including other variables in addition to power output. Unfortunately, none of the equations that we developed using additional variables estimated $\dot{V}O_2$ any better than just using power output, and the accuracy of estimating submaximal $\dot{V}O_2$ during cycle ergometry was less than desirable. The SEE

TABLE 5. Percent of predicted $\dot{V}O_2$ values within specified milliliters per minute at 60% of $\dot{V}O_{2max}$ (pre-training).

Equation	50 mL	100 mL	150 mL	200 mL
ACSM (2)	22%	42%	58%	71%
Berry et al. (5)	12%	26%	38%	48%
Lang et al. (13)	19%	37%	57%	70%
Latin & Berg (14)	23%	43%	58%	70%
Londeree et al. (17)	16%	32%	46%	55%
HERITAGE-1	25%	51%	70%	84%

References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 5. Berry, M. J., J. A. Storsteen, and C. M. Woodard. Effects of body mass on exercise efficiency and $\dot{V}O_2$ during steady-state cycling. *Med. Sci. Sports Exerc.* 25:1031–1037, 1993; 13. 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.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994; 17. Londeree, B. R., J. Moffitt-Gerstenberger, J. A. Padfield, and D. Lottmann. Oxygen consumption of cycle ergometry is nonlinearly related to power output and pedal rate. *Med. Sci. Sports Exerc.* 29:775–780, 1997.

TABLE 6. Percent of predicted $\dot{V}O_2$ values within specified milliliters per minute at 60% of $\dot{V}O_{2max}$ (post-training).

Equation	50 mL	100 mL	150 mL	200 mL
ACSM (2)	27%	51%	68%	83%
Berry et al. (5)	6%	14%	23%	35%
Lang et al. (13)	10%	23%	36%	51%
Latin & Berg (14)	29%	49%	65%	79%
Londeree et al. (17)	18%	33%	45%	58%
HERITAGE-1	22%	41%	59%	76%

References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*, 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 5. Berry, M. J., J. A. Storsteen, and C. M. Woodard. Effects of body mass on exercise efficiency and $\dot{V}O_2$ during steady-state cycling. *Med. Sci. Sports Exerc.* 25:1031–1037, 1993; 13. 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.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994; 17. Londeree, B. R., J. Moffitt-Gerstenberger, J. A. Padfield, and D. Lottmann. Oxygen consumption of cycle ergometry is nonlinearly related to power output and pedal rate. *Med. Sci. Sports Exerc.* 29:775–780, 1997.

and total error were 9–11% at 60% of $\dot{V}O_{2max}$. There were unknown significant individual differences that we have been unable to account for.

We also compared the new equation we developed, HERITAGE-1, with previously published equations (2,5,13,14,17). The ACSM (2), HERITAGE-1, and Latin and Berg (14) equations were the most accurate, while the equations of Berry et al. (5) and Londeree et al. (17) were the least accurate. These latter equations, which took into account pedal rate, performed the poorest with both pre- and post-training data. The equation of Berry et al. (5) overestimated, while the equations of Londeree et al. (17) underestimated the measured $\dot{V}O_2$. Had pedal rate been varied in the current study, these two equations may have performed better.

Post-training the ACSM (2) equation was the only equation that produced estimated $\dot{V}O_2$ values that were not significantly different than the measured values; however, there was little difference between the ACSM (2), Latin and Berg (14), and HERITAGE-1 equations. When the $\dot{V}O_2$ values were converted to milliliters per kilogram per minute, the difference among them in SEE and E was only 0.0 to 0.3 $mL \cdot kg^{-1} \cdot min^{-1}$. Each of the previously published equations (2,5,13,14,17) had lower mean difference, SEE, and E on the post-training data than on the pretraining data. This was probably a result of improved mechanical efficiency and/or higher power output during post-testing.

The equations of ACSM (2), Lang et al. (13), Latin and Berg (14), and HERITAGE-1 had different slopes and intercepts. The slopes in milliliters per watts were 9.76, 11.33, 11.59, and 12.2 for Latin and Berg (14), HERITAGE-1, Lang et al. (13) and ACSM (2), respectively. Figure 1 gives a graphic comparison of these four equations using a 70-kg person. The values would be slightly different for individuals of different body masses.

The value estimated by the ACSM (2) equation was 164 $mL \cdot min^{-1}$ lower than that estimated by HERITAGE-1 at 50 W, but since the ACSM equation has the steepest slope, the value estimated by the ACSM equation was only 33 $mL \cdot min^{-1}$ lower than that estimated by HERITAGE-1 at 200 W.

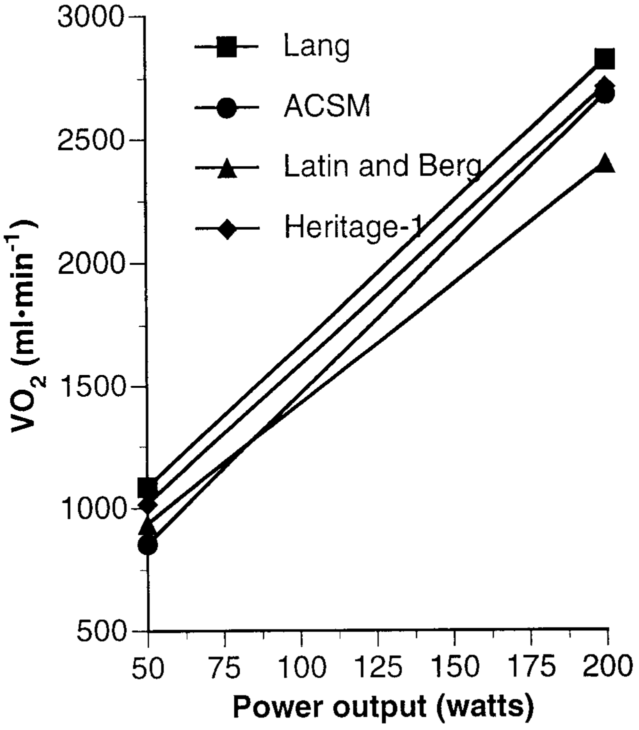

Figure 1—Comparison of equations of ACSM (2), Lang et al. (13), Latin and Berg (14), and HERITAGE-1 using a 70-kg person. References: 2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*, 5th Ed. Baltimore: Williams and Wilkins, 1995, pp. 273–279; 13. Lang, P. B., R. W. Latin, K. E. Berg, and M. B. Mellion. The accuracy of the ACSM cycle ergometry equation. *Med. Sci. Sports Exerc.* 24:272–276, 1992; 14. Latin, R. W. and K. E. Berg. The accuracy of the ACSM and a new cycle ergometry equation for young women. *Med. Sci. Sports Exerc.* 26:642–646, 1994.

Previous studies (3,13–15) have shown the ACSM equation to underestimate $\dot{V}O_2$ by a mean difference of up to 234 $mL \cdot min^{-1}$. The ACSM equation underestimated $\dot{V}O_2$ in the current study, but the difference was much less than 234 $mL \cdot min^{-1}$ and the difference was less post-training than pretraining. The ACSM equation has a steeper slope but lower intercept than Lang et al. (13), Latin and Berg (14), or HERITAGE-1. The lower intercept kept it from performing as well at lower power outputs, but the steeper slope allowed its performance to improve at higher power outputs.

In conclusion, 1) HERITAGE-1, which used only power output as an independent variable, was as accurate in estimating submaximal $\dot{V}O_2$ during cycle ergometry as other new equations developed using additional independent variables; 2) HERITAGE-1, while slightly better than the equations of ACSM (2) and Latin and Berg (14) using pretraining data, was no better when using post-training data; and 3) all three of these equations were superior to the equations of Berry et al. (5) and Londeree et al. (17).

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