***JEP*online**
Journal of Exercise Physiologyonline
Official Journal of The American Society of Exercise Physiologists (ASEP)
ISSN 1097-9751
An International Electronic Journal
Volume 2 Number 4 October 1999

Fitness and Training

PREDICTION OF maxVO_2 FOR WOMEN: ADAPTATION OF THE FOX CYCLE ERGOMETER PROTOCOL

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ABSTRACT

PREDICTION OF maxVO_2 FOR WOMEN: ADAPTATION OF THE FOX CYCLE ERGOMETER PROTOCOL. LYNN A. DARBY[1] AND ROBERTA L. POHLMAN[2]. ***JEP*ONLINE, 1999, 2(4):13-19.** Fox (1973) proposed a simple method for predicting maximal oxygen consumption (maxVO_2) from the heart rate (HR) response to 5 minutes of cycle ergometry at a power output of 150 W. This equation was established for males only, but it has been suggested for use with women (Heyward, 1988) even though a workload of 150 W may be too intense for women. Therefore, the purpose of this study was to construct an equation for women to predict maxVO_2 using the format of the Fox cycle ergometer protocol but for different exercise intensities (Part 1). In addition, a cross-validation of the regression equation was performed on an independent sample of women (Part 2). Female subjects (n = 63) completed a discontinuous incremental exercise protocol to fatigue. The exercise intensity began at 90 W, each stage duration was 5 min, stages were separated by 10 min of rest, and power outputs increased by 30 W/stage. HR data were collected for women at workloads of 90, 120, 150, and 180 W. Simple linear and multiple regression analyses were computed. HR at 90 W (r=-0.69) was a significant predictor of maxVO_2 (mL/min); however, when age and body weight were added to HR at 90W as independent variables then the multiple regression equation was:

Fox equation for women: Y = 4093 – (35 x age [yrs]) + (9 x BW [kg]) – (11 x HR [b/min])
where Y = maxVO_2 in mL/min; ($p<0.0001$), R= .74, R^2= 0.55, SEE=250 mL/min

For the cross validation, 15 women completed the Fox CE protocol for women (90 W), and then exercised to exhaustion. There was no significant difference between the measured maxVO_2 and predicted maxVO_2 from the Fox equation for women (Mean±SD = 2351± 293; 2406±217 mL/min; t= -1.45, $p \leq 0.1690$, r = 0.74). MaxVO_2 predicted from the Fox equation for women and predicted from the validation group data using other CE equations were compared to the criterion (measured maxVO_2). The Fox equation for women was a good predictor of measured maxVO_2 (r=0.88, SEE=109 mL/min, CV=9.0 %). It is suggested that when using the Fox CE protocol, the prediction of maxVO_2 for women be estimated from the Fox equation for women.

Key Words: prediction, women, submaximal exercise testing, heart rate

INTRODUCTION

Submaximal exercise testing is often used to predict maximal oxygen consumption (maxVO_2) from an individual's heart rate (HR) at a certain submaximal workload (3-5). Maximal oxygen consumption is then predicted using an established regression equation (3). Although the accuracy and validity of these submaximal tests has been questioned (4,5), they are still used widely for the prediction of maxVO_2 in practical settings (e.g., fitness centers). Problems inherent in submaximal testing, such as nonlinearity of VO_2 and HR over the entire range of effort, changes in heart rate not related directly to work output, and population specificity are common. However, submaximal tests are useful for estimating aerobic fitness without undue stress to the subjects, and are more suited to the elderly or individuals with known cardiovascular or metabolic diseases. Submaximal tests are also more easily, cheaply and rapidly administered to large numbers of subjects (3), and are more accurate when used to repeatedly assess an individual's fitness in response to an intervention (3-6).

In 1973, Fox (1) proposed a simple method for predicting maxVO_2 from the heart rate response of college-age males from the heart rate response to 5 min of cycle ergometry at 150 W (Table 1). It has been suggested that this equation could be used with women, however, the 150 W power output may be too great for many women (2). The Fox protocol differs to others in that the pedaling rate is 60 rev/min. Astrand and Rodahl (7) have suggested that optimal (for economy) pedaling frequencies exist between 40-70 rpm. Therefore, the establishment of an equation for women at a different rev/min than the standard 50 rev/min, and at a lower power output would allow the tester more flexibility in choosing a protocol appropriate for the subject to be measured, and his/her testing goals.

The purposes of this study were to construct a Fox equation for women to predict maxVO_2 from power outputs less than 150 W (Part 1), and cross validate the equation for women using a second subject sample (Part 2).

METHODS

Part 1: Development of the Equation for Women

Female subjects (n=63) were recruited at two universities from the mid-west of the Unites States. All subjects completed informed consent statements and medical history questionnaires. The discontinuous bicycle ergometer protocol consisted of a series of 5 min exercise bouts on a Monark bicycle ergometer. The exercise intensity began at 90 W, each stage duration was 5 min, stages were separated by 10 min of rest, and power output increased by 30 W/stage until exhaustion. A constant velocity of 60 rev/min was maintained throughout the test. The test session was terminated when the subject could no longer maintain the cadence of 60 rpm, reached volitional exhaustion, achieved a leveling or a decrease in VO_2 with increasing workloads, and/or achieved a respiratory exchange ratio (RER) greater than 1.0 (8).

Heart rates were recorded via a 12-lead electrocardiogram (Quinton 4000 or Marquette Case I) during minutes 4 and 5 of each workload. VO_2 was determined from analysis of expired air analyzed using a Sensormedics 2900 Metabolic Measurement Cart or Gould 9000 IV. Standard calibration procedures were completed for each system. In addition, all subjects completed measurements for body weight, height, and hydrostatic weighing. Residual volume for the women was estimated from vital capacity using the Wilmore formula (9), and percentage body fat was determined using the Brozek equation (10).

Simple linear regression equations and standard error of the estimates were computed for the HR and power outputs at 90 W and 120 W (11). Multiple regression analyses were calculated to determine whether the addition of other variables (e.g., age, body weight, height, % body fat, etc.) would increase the strength of the prediction (11). Descriptive statistics for all variables were calculated for this original group used to establish the prediction equation (n = 63) (11).

Reliability of the measurements

In order to assure that differences in measurements did not occur due to testing site, samples of 15 participants were chosen from each site, and submaximal VO_2 at 90 W were compared. When an independent t-test was calculated, there was no

Table 1: Equations used to compare maxVO2 prediction to the Fox equation for women.

Author	*Equation*	*Sex*
Fox (1)	$maxVO_2$ (mL/min) = 6300 – (19.26 x HR [@150 W, b/min])	Men
Jones (12)	$maxVO_2$ (L/min) = (0.046 x Ht [cm]) – (0.021 x age [yrs]) – (0.62 x Sex) - 4.31	Men,
	where for sex, men = 0, women = 1	Women
Storer (13)	$maxVO_2$ (mL/min) = (9.39 x max Watts) + (7.7 x BW [kg]) – (5.88 x age [yrs]) + 136.7	Women
Astrand-Ryhming (4,14)	$maxVO_2$ (L/min) = submax VO_2 * [((220-age [yrs])-72 / (HRsubmax –72)]	Women
	where submax VO_2 (L/min) = (Power [Watts] x 0.012) + 0.3	

Table 2: Physical characteristics and physiological responses of the original data group and the cross-validation group of women completing the Fox cycle ergometer protocol (90W) for submaximal and maximal work (n=63)

	Original group (N=63)	*Cross-validation group (n=15)*
Physical		
Age (yr)	20.8 ± 2.0	19.5 ± 1.4[c]
Height (in)	65.3 ± 3.5	68.1 ± 3.6
Weight (kg)	59.7 ± 8.5	62.9 ± 11.0
% Body Fat	23.2 ± 5.2	22.3 ± 5.2
Submaximal Work (90 W) [a]		
HR (beats/min)	150 ± 21	143 ± 17
% HR max (age predicted)	75 ± 10	71 ± 8
Maximal Work		
predicted VO_2 (mL/min) [b]	2256 ± 272	2406 ± 217 [d]
measured VO_2 (mL/min)	2215 ± 373	2351 ± 293 [d]
measured VO_2 (ml/kg/min)	37.5 ± 6.6	36.6 ± 5.2 [d]

[a] Measurements taken during minute 5 of work.
[b] Using the Fox equation for women (Darby and Pohlman)
[c] Significantly less than the original group; $p \leq 0.05$
[d] No significant difference between predicted and measured $maxVO_2$

significant difference in VO_2 due to test site (df =28, t=1.353, *p*=0.1870; Site 1 = 1394 ± 138 mL/min, Site 2 = 1324 ± 146 mL/min (11). Therefore, the data were pooled from the two test sites.

Part 2: Cross validation of the Fox equation for Women

To cross-validate the equation, a separate group of subjects was tested (11). Fifteen women completed the Fox protocol for women and then rode to exhaustion without the 10 min rest intervals between each stage using incremental loads of 30 W. VO_2 and HR were determined during each minute of the test as described for Part 1. Predicted $maxVO_2$ for each subject was calculated using the multiple regression equation established from the original group of women (n=63). A paired t-test was calculated to compare measured and predicted $maxVO_2$. Descriptive statistics for all variables were calculated for the cross-validation group (n = 15). Mean percentage error was calculated as (Predicted $maxVO_2$ - measured $maxVO_2$ / measured $maxVO_2$) x 100.

The data of HR at 90 W were also used to estimate $maxVO_2$ using other CE equations for predicting $maxVO_2$ (Table 2).

A one-way repeated measures ANOVA with a Tukey's HSD *post hoc* test was calculated to determine if differences were present among the predicted $maxVO_2$ values from the multiple equations. Pearson product correlation coefficients were calculated between all predicted $maxVO_2$ and the measured $maxVO_2$ values.

RESULTS

Part 1

Means and standard deviations for physical characteristics and physiological responses to submaximal (90 W) and maximal workloads for the original data group are presented in Table 3. When the heart rates at different workloads were analyzed, HR at 90W and HR at 120 W were significant predictors of $maxVO_2$ when expressed as mL/min, but not significant when expressed relative to body weight in mL/kg/min. HR at 90 W was chosen as the best predictor of $maxVO_2$ in mL/kg/min because of the 63 participants only 31 had HR's < 170 mL/min for 120 W. At 90 W subjects were working at a VO_2 of 1340 ± 150 mL/min which was at 64 ± 14 % $maxVO_2$. In addition, at 90 W the HR-VO_2 simple linear regression results were: n= 63, r=

Table 3: Comparison of $maxVO_2$ measured and predicted from various cycle ergometer equations using data for the cross-validation group[a]

Equation	*n*	*Variables*	*R or r*	*SEE (mL/min)*	*$maxVO_2 \pm SD$*	*Coefficient of Variation (%)*[d]
Measured	---	---	---	---	2351 ± 293	12.5
Fox women	63	HR-90 W, BW, age	.74	250	2406 ± 217	9.0
Fox men[b]	87	HR-150 W	.76	246	3552 ± 331*	9.3
Jones	50	Ht, Age, Gender	.87	458	2617 ± 411*	15.7
Astrand-Ryhming	44	HR submax, Workload submax			2650 ± 645	24.3
Storer[c]	116	$Watts_{max}$, BW, age	.93	147	1915 ± 86*	4.5

*$p \leq .05$; significantly different from measured
[a]Calculated from cross-validation group data (n=15)
[b] Calculated from HR-90 W
[c] Calculated from $Watts_{max}$ which was 150 W
[d] CV = (σ/mean)*100 for $maxVO_2$ calculated from each equation

0.69, SEE=270 mL/min versus at 120 W, n=31, r= -0.54, SEE = 257 mL/min.

Results from the multiple regression equation indicated that body weight and age were also significant predictors of VO_2 along with HR at 90 W. The multiple regression equation was:

$$maxVO_2\ (mL/min) = 4093 - (35 \times age\ [yrs]) + (9 \times BW\ [kg]) - (11 \times HR\ [b/min])$$
$$(p<0.0001),\ R=0.74,\ SEE=250\ mL/min)$$

The mean for measured $maxVO_2$ was 2215±373 mL/min and is shown in Table 2. The mean for the predicted VO_2 max using the 63 subjects was 2256±272 mL/min. There was no significant difference between the predicted and measured $maxVO_2$ (df=62, t=-1.326, *p*=.1896). Maximal HR was 189±9 beats/min. The simple linear regression for predicted $maxVO_2$ versus measured max VO_2 for the 63 participants from the original sample is shown in Figure 1 with r=0.74 and SEE=184 mL/min.

Part 2

A separate group of subjects (i.e., the cross-validation group) was recruited to compare measured $maxVO_2$ to predicted $maxVO_2$ calculated using the Fox equation for women. There was no significant difference between the predicted and measured $maxVO_2$ values for this cross-validation group of women (see Table 2) with the mean difference = 55 mL/min , df=14, t=-1.450, p=.1690. All other physical characteristics between the original equation group and validation group were not significantly different with the exception of age (see Table 2). The simple linear regression for predicted $maxVO_2$ versus measured $maxVO_2$ for the cross-validation group is shown in Figure 2. Because it has been suggested that the Fox men's equation could be used for women, the residuals for the Fox men's equation versus the Fox women's equation to predict $maxVO_2$ for the cross-validation group are shown in Figure 3. The residuals (i.e., difference between each predicted and measured $maxVO_2$) are plotted against the measured $maxVO_2$. As can be observed the Fox men residuals are much greater (i.e., approximately 500-1600 mL/min) than the Fox women's equation residuals (i.e., no more than 200 mL/min above or below the measured values). Hence, the Fox women's equation is a better predictor of the measured $maxVO_2$ for these women.

To compare the Fox equation for women to other CE protocols, HR and demographic data were used in the other CE equations. There was a significant difference among the predicted and measured $maxVO_2$ (see Table 3) (F=54.11, p<.0001). Tukey's HSD tests revealed that the predicted $maxVO_2$ computed from the Fox equation for women was not significantly different from the measured $maxVO_2$, the criterion. All other mean $maxVO_2$ from the other equations except the Astrand-Ryhming (4) were significantly different from the measured $maxVO_2$. Correlation coefficients, standard error to the estimates, and mean percentage errors for the predicted maxVO_2 and the measured maxVO_2 max are shown in Table 4.

DISCUSSION

Although there are inherent problems that exist with the use of submaximal testing to predict maxVO_2, the results from the present study indicate that a separate, multiple regression equation was necessary to predict the maxVO_2 for women when using the Fox bicycle ergometer protocol (90 W for 5 minutes at 60 rev/min). An initial workload of 150 W was too great for many of the women and did not elicit a submaximal HR (i.e., < 170 beats/min). In addition, Storer (13) reported, "It has been well established that maxVO_2 is lower in females if expressed in absolute terms (mL/min)". This may be due to the fact that the amount of muscle mass in the legs often determines total work production on a bicycle ergometer. In general, women have less total muscle mass, lower hemoglobin concentrations, and smaller maximal cardiac outputs than men[15] and therefore, may not have as great an absolute maxVO_2 on the CE. As Wells (15) has pointed out there are more similarities than differences between the genders, and some women may be able to maintain 150 W for the 5 min of the Fox protocol (men) (1). However, based on the results from the present study, these general differences in physiological characteristics most likely affect maximal performance, change the slope of the HR-VO_2 regression line and thus, necessitate a specific equation for women.

Error from assumptions of submaximal testing

The error that can be associated with predicting maxVO_2 from submaximal HR data are due to violations of the assumptions of submaximal testing that are: 1) a steady state VO_2 is achieved at a workload; 2) a linear relationship exists for HR and VO_2, and that the HR data point is measured on a portion of the HR-VO_2 regression line that is linear (i.e., at a workload > 45% of maxVO_2 so that increases in VO_2 are due to increases in HR and not stroke volume); 3) that the maximal heart rate for given age is consistent; 4) mechanical efficiency in completing the exercise is essentially the same for all subjects (3).

Of these criteria that could be measured or controlled in the present study, the first two criteria were met by the original group in that the mean HR was 150 (b/min) (i.e., between 120 and 175 (b/min) and the relative workload was 64% of maxVO_2. For the third criteria, the measured max HR for the subjects was 189±9 beats·min^{-1} whereas the estimated max HR (220-age) would be approximately 198 b/min. The subjects in the

Figure 1: Regression equation of measured max VO_2 versus predicted max VO_2 from the Fox equation for women (n = 63): max VO_2 (mL/min) = 4093 – (35 x age [yrs]) + (9 x BW [kg]) – (11 x HR (b/min).

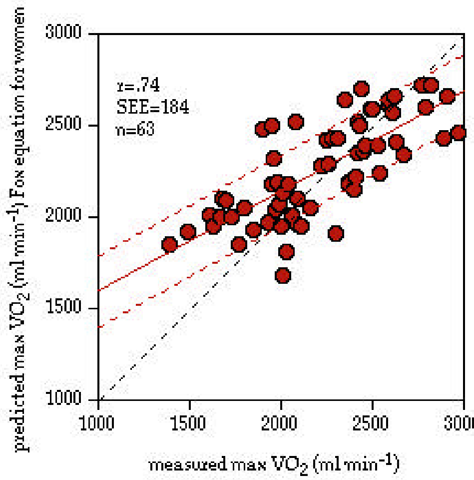


Figure 2: Plot for the cross-validation group of predicted maxVO_2 using the Fox equation for women versus the measured maxVO_2.

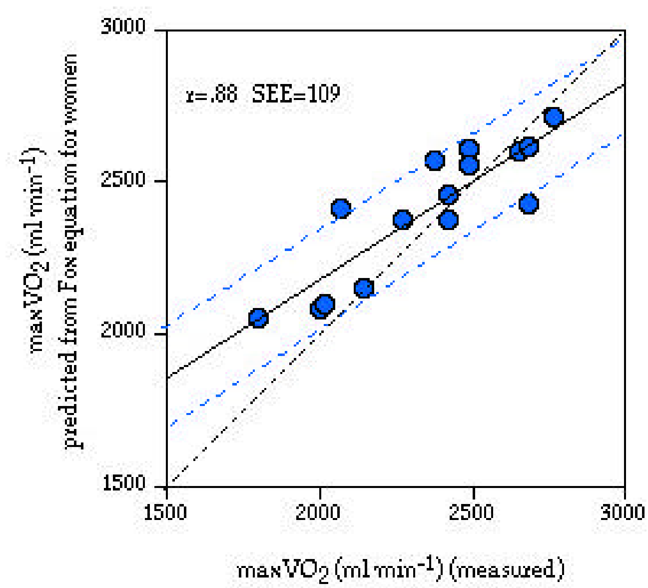
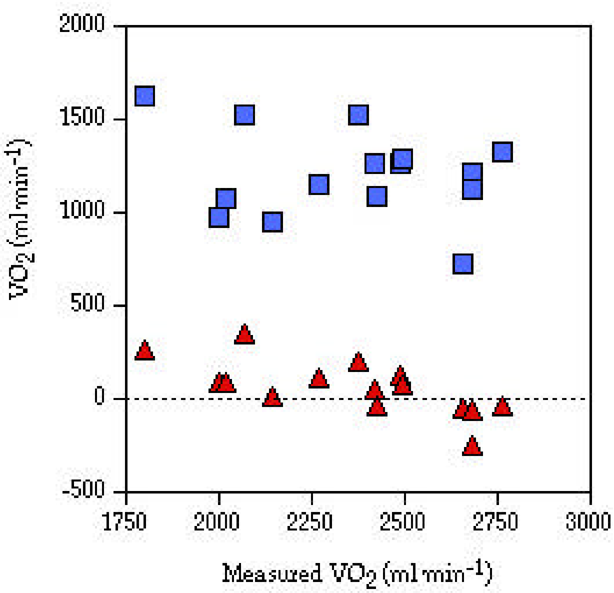


Table 4: Criterion versus predicted VO_2 max correlations

Equation	r	SEE (ml·min^{-1}) [a]	SEE % Mean [b]	Mean Error % [c]
Fox women	0.88*	109	4.6	2.3
Fox men	0.71*	241	10.3	51.1
Jones	0.13	423	18.0	11.3
Astrand-Ryhming	0.72*	465	19.8	12.7
Storer	0.62*	70	3.0	-18.5

*$p \leq .05$
[a] SEE = $[\Sigma(Y-Y')^2/N]^{-1/2}$
[b] (SEE/Mean measured maxVO_2) x 100
[c] (Predicted maxVO_2 - measured maxVO_2 / measured maxVO_2) x 100

Figure 3: Residuals of the predicted maxVO2 for the Fox equation for men and women using data from the cross-validation group (n=15).



present study typically stopped cycling when the workload could not be moved any longer. McArdle, Katch and Pechar (16) have reported that bicycle ergometer maxVO_2 are 6-11% lower on the bicycle ergometer as compared to the treadmill. In the present study, this was true for HR max when measured, seated CE values were compared to the age predicted HRmax. However, the amount of error introduced by intersubject variability in max HR when using submaximal prediction equations has been reported by Davies (17) as small with a coefficient of variation of ~5%.

For the fourth criteria, the consistency of mechanical efficiency among subjects was not measured in the present study, but the submaximal VO_2 in the present study was recorded as 1340±150 mL/min at 90 W. The coefficient of variation, a relative measure of variation, for this power output would be ~11%. The coefficient of variation for Fox's original group for 150 W was ~6%. A number of factors can affect mechanical efficiency (i.e., leg length, crank radius, use of toe-clips), but are not commonly controlled for in submaximal testing. It may be interesting to note that the submaximal VO_2 at 90 W estimated from other cycle ergometry equations that are not gender specific and that have been established to predict VO_2 at submaximal exercise intensities from power output data, were 1289±30 mL/min for the ACSM equation (3), and 1495±30 mL/min for the Lang et al. (18) and Latin et al. (19) equation established using men. These results may provide circumstantial evidence that the women in the present study worked at a lower VO_2 than what might be predicted for men at the same workload, and hence would need a gender specific equation. In addition, Astrand-Ryhming (4) reported that females attained a lower VO_2 at any workload as compared to males (4) and this may be another reason for using the gender specific, Fox equation for women.

Comparison to other CE prediction equations

Given these limitations and assumptions of submaximal testing, when the predicted maxVO_2 from the Fox equation for women using data from the validation group was compared to other equations (see Tables 3 and 4), the SEE, and SEE % Mean are comparable to other CE protocols. In reviewing submaximal CE prediction equations, Cardus (20) reported that usually there is a 300 mL/min difference between estimated and actual maxVO_2 from CE protocols with estimates lower than the measured VO_2. In the present study, the mean difference between measured and predicted maxVO_2 for the original group was 41 mL/min, and for the validation group this was 55 mL/min. In contrast to Cardus (20), the proposed equation for women overpredicted rather than underpredicted maxVO_2. The other CE equations, Storer (women) (13); Jones (women) (12); Fox (men) (1) and Astrand-Ryhming (4,14), were chosen because these were comparable for one or more of the variables of gender, time frame, pedal revolution, and workloads used in the Fox equation for women. It should be noted that the Storer protocol (13) is a maximal workload test, in that maxVO_2 is predicted from a maximal workload in Watts. The maximal workloads for the validation group were used to predict max VO_2 using the Storer equation. For the Jones equation (12), only age and height are used and not an actual submaximal data (e.g., HR). Although these are similar in that these are prediction equations, these are not the same as using a submaximal HR to predict maxVO_2. These other equations were presented for comparison purposes, not as substitutes for the presented Fox protocol for women. The intent of the present study which was to complete a submaximal prediction equation for women, if the Fox equation for men was not appropriate.

Although the r value for the Fox equation for women is moderate (r=.74) it is comparable to the r value for the Fox equation for men (see Table 3) (1). Fox (1) stated that the advantages to using the Fox protocol were that the problem with linearity of HR and VO_2 is negated because one point is used to predict maxVO_2, and that a different rate of pedaling, 60 rev/min, is used. This cycling rate is greater than some bicycle ergometer protocols which usually use 50 rev/min. Sharkey (21) has indicated that untrained subjects perform better at 60-70 rev/min because greater workloads cannot be sustained as easily at 50 rev/min. In addition, the difference between the present protocol and the widely used Astrand-Rhyming protocols (4,14) is that the present method selects a standard level of work whereas the Astrand-Rhyming method elicits a HR of 125-170 with workload adjustments made if necessary during the CE test.

CONCLUSIONS

Regardless of the problems with submaximal testing, it is still used widely in the field of exercise physiology as a measure of cardiorespiratory fitness especially when maximal testing cannot be performed. Information from submaximal prediction equations is best used in intraindividual testing to ascertain an individual's fitness without the cost, risk, time, and effort on the part of the subject (3). From the data presented, if the Fox cycle ergometer protocol is used with female subjects, it is suggested that maxVO_2 be predicted from the Fox equation for women rather than the equation for men. As Heyward (2) has suggested, a lower workload for women was shown to be necessary in this sample of participants, however, these submaximal HR responses at 90 W should not be used in the original Fox (1) equation for men. Predicted maxVO_2 should be interpreted carefully and used within the guidelines and limitations for any submaximal CE test.

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ACKNOWLEDGMENTS

The authors would like to thank Heping Zhang and Michelle Cwiklinski for assistance in data collection, and Dr. Michael Liang for editorial assistance.

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