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PREDICTION OF VO_2MAX FROM AN INDIVIDUALIZED SUBMAXIMAL CYCLE ERGOMETER PROTOCOL

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ABSTRACT

CENGIZ AKALAN, ROBERT A. ROBERGS, LEN KRAVITZ. **Prediction Of VO_2max From An Individualized Submaximal Cycle Ergometer Protocol. *JEPonline*** 2008;11(2):1-17. We hypothesized that a large proportion of the error of VO_2max prediction comes from individual differences in heart rate responses to submaximal exercise, and that if these differences could be decreased the accuracy of VO_2max prediction would increase. Eighty (43 male, 37 female) sedentary to highly trained, healthy volunteers first completed a self-report physical activity assessment (Lo-Par), and then performed a modified YMCA protocol with 4-minute stages, a second submaximal test involving an individualized ramp submaximal protocol that was terminated at 80% of their cycle ergometer age-predicted maximum heart rate. Exercise and five-minute recovery heart rate data were collected. A ramp cycle ergometer protocol with expired gas analysis was used to measure actual VO_2 max. Multiple regression analysis produced a model resulting in an R^2 = 0.867 and SEE = 4.23 mL/kg/min, with a prediction equation as follows: VO_2 max (mL/kg/min) = 46.103 + (-0.353*Body Weight) + (0.683*Watts/min) + (-5.995*Gender) + (0.165*Delta Recovery Heart Rate) + (2.816*Recovery Heart Rate Non-Linear K) + (0.0138*Lo-PAR Exercise) + 4.234. T-test statistics showed no statistically significant differences between observed and predicted VO_2max. Mean difference between YMCA, ACSM, and Astrand-Ryhming Nomogram estimated VO_2 max and observed VO_2 max were significant. However, the new equation did not decrease the error of prediction to the extent hypothesized.

Key Words: Multiple Regression, Fitness, Exercise

INTRODUCTION

The measure of the maximal rate of whole body oxygen consumption during exercise (VO_2max) has a history dating back to the pioneering work of A.V. Hill in the 1920s. Traditionally, VO_2max has been interpreted as a measure of the maximal capacity of the cardiorespiratory system to acquire oxygen, circulate it to working muscle, where muscle can the extract and utilize oxygen in mitochondrial respiration to meet the energy needs of muscle contraction. The measure of VO_2max has therefore been invaluable in quantifying endurance fitness and the status of the cardio-respiratory and muscular systems for all individuals ranging from the athlete to the sedentary and diseased.

As the measurement of VO_2max needs expensive equipment, and requires individuals to exercise to volitional fatigue, it is not suitable for use when testing a large number of individuals, or when individuals might be placed at an unacceptable health risk when exercising to maximal exertion. Consequently, numerous procedures have been researched and validated to estimate VO_2max from submaximal exercise or procedures not involving exercise at all (Table 1-3).

Table1. Summary of Treadmill VO_2 max Tests.

Type	Study	N	Ages	Gender/Health	Predictor Variables	R	SEE
Treadmill	**ACSM (Walking) (ml/kg/min)**	-	-	M, F Healthy	Grade, Time	-	-
	ACSM (Running) (ml/kg/min)	-	-	M, F Healthy	Grade, Time	-	-
	Ebbeling (ml/kg/min)	67	20-59	M	Walk speed, Age, HR, Gender	0.96	5.0
		72	-	F	Walk Speed, Age, HR, Gender		
	Widrick (ml/kg/min)	145	20-59	M Healthy	Weight, Age, Gender, Time, HR	0.91	5.26
	Wilmore (ml/kg/min)	42	18-30	M Healthy	Weight, Age, Gender, Time, HR	0.76	5.0
	Bruce (Maximal) (ml/kg/min)	44	-	M Active	Time	0.906	-
		94	-	M Sedentary	3.298 (time) + 4.07	0.906	-
		97	-	M Cardiac	2.327 (time) + 9.48	0.865	-
		295	-	M, F Healthy	Gender, Time	0.920	-
	Foster (Maximal) (ml/kg/min)	230	-	M Varied	Time 1, Time2, Time3	0.977	3.35
	Froelicher (Maximal) (ml/kg/min)	1,025	20-53	M Healthy	Time	0.72	4.26
	Bonen (L/min)	100	7-15	M	HR, VCO_2, VO_2, Age	0.95	0.170
	Metz (ml/kg/min)	60	12-13	M	HR, VO2, RER	0.70	-
	Metz (ml/kg/min)	60	14-15	M	HR, VO2, RER	0.48	3.8
	Hermiston	28	25-45	M	Age, FFV, HR, F_e CO_2, V_T, RER	0.90	-

Table2. Summary of Cycle Ergometer VO_2 max Tests.

Type	Study	N	Ages	Gender/Health	Predictor Variables	R	SEE
Cycle Ergometer	**ACSM (ml/min)**	-	-	M, F Healthy	Kg/min, Weight	-	-
	ACSM (L/min)	-	-	M, F Healthy	Watts	-	-
	Latin (ml/min)	110	18-38	M Healthy	Kg/min, Weight	0.96	154.0
	Legge (L/min)	15	20-29	M Trained	?HR (max HR-zero load HR)	-	0.39
		10	-	M Untrained	?HR (max HR-zero load HR)	-	0.32
	Wasserman (ml/min)	-	-	-	Watts	-	-
	Fox (ml/min)	87	17-27	M	HR-at5th min at 150 Watts	0.76	246.0
	Astrand (L/min)	27	18-30	M Healthy	Nomogram	-	0.28
		31	-	F Healthy	Nomogram	-	0.27
	Siconolfi (L/min)	25	20-70	M Healthy	VO2; Astrand, Age	0.86	0.36
		28	-	F Healthy	VO2; Astrand, Age	0.97	0.20
	Legge (L/min)	25	20-29	M Healthy	Nomogram using ?HR (max HR- zero load HR)	0.98	0.17
	Patton (Maximal) (ml/min)	15	-	M Healthy	Watts	0.89	-
		12	-	F Healthy	Watts	0.88	-
	Storer (Maximal) (ml/min)	115	20-70	M Healthy	Max Watts, Weight, Age	0.94	212.0
		116	-	F Healthy	Max Watts, Weight, Age	0.93	147.0
	Mastrapaolo (L/min)	13	43-61	M	RER, DBP, V_E, F_e O_2, Work (kpm)	0.93	0.172
	Siconolfi (L/min)	63	20-70	M, F	Age, VO2 predicted from Astrand Nomogram	0.94	0.248

Assessment of the research summarized in Table 1-3 reveals the frequent use of exercise heart rates in VO_2max prediction. Although the HR response to any given workload has been shown to roughly reflect the physical working capacity of an individual, there are limitations associated with the use of HR as a single independent variable to estimate VO_2max. For instance, Davies et al. (1) notes that VO_2max is consistently under-estimated due to the asymptotic, rather than linear, pattern of the HR response as one approaches VO_2max. Another problem with these methods is the assumption required for a target maximal HR using age as the only predictor variable. Many laboratories report standard deviations for age-predicted maximal HR in the order of 10-15 beats/min (2). Thus, the estimated maximal HR is accurate for some, while either high, or low for an unacceptably large proportion of other individuals. Ultimately, such a large standard deviation has the effect of reducing the precision with which VO_2max can be predicted from submaximal HR.

Table3. Summary of Field VO_2 max Tests.

Type	*Study*	*N*	*Ages*	*Gender/Health*	*Predictor Variables*	*R*	*SEE*
Stepping	**ACSM (ml/kg/min)**	-	-	M, F Healthy	Steps/min, Height	-	-
	McArdle (ml/kg/min)	41	18-22	F Healthy	Recovery HR	0.92	2.9
		-	18-22	M Healthy	Recovery HR	-	-
Bench	**Jette (ml/kg/min)**	24	15-74	F	Age, Weight, VO2, Recovery HR	-	4.1
	Jette (ml/kg/min)	35	15-74	M	Age, Weight, VO2, Recovery HR	-	4.1
Field Tests	**Cooper (ml/kg/min)**	115	17-52	M	35.97(miles after 12 min) - 11.29	0.90	-
	Kline (L/min)	343	18-23	M, F	Weight, Age, Gender, Time, HR	0.93	0.325
	Coleman (ml/kg/min)	90	20-29	M, F Healthy	Weight, Age, Gender, Time-1-mile walk, HR	0.79	5.68
	Doolittle	9	14-15	M	12-min run/walk distance	0.90	-
	Getchell	21	18-25	F	1.5-mile run time	0.46	-
	Ribisl (ml/kg/min)	24	30-48	M	Age, Weight, 00 yards, 200 yards, 2-mile run time	0.95	1.97
	Ribisl (ml/kg/min)	11	18-22	M	Age, Weight, 00 yards, 200 yards, 2-mile run time	0.94	1.55
	Kline (L/min)	343	30-69	M, F	1-mile walk time, Age, HR, 1-4 weight	0.93	0.325
Non-exercise equations	**Wier (ml/kg/min)**	2417 M 384 F	21-82	M,F	Waist Girth	0.81	4.80
					% Fat	0.82	4.72
					BMI	0.80	4.90
	Sanada (L/min)	60 M	21-	M	Lower Leg Skeletal Muscle Mass	0.55	-
					Left Ventricular Internal Dimension at End-diastole	0.74	-
					Left Ventricular Internal Dimension at End-systole	0.72	-
					Stroke Volume	0.72	-

Of the numerous predictive equations reported in the literature, most do not present cross-validation results (3-7), many were developed on age/sex specific populations (5,8-11), and several provide none or high values of the standard error of the estimate (SEE) measure which reflects the inaccuracy of VO_2max prediction (12-28).

The purpose of developing prediction equations is to provide a simpler means of determining a complex measurement by using variables that are easily measured. The selection of important variables that are likely to influence the VO_2max, along with good research techniques and equipment, are important factors that affect the validity of the prediction equation (29). To develop better prediction equations, researchers need to complete measurements on a large number of individuals and use variables likely to influence the criterion. In this case, we hypothesized that if the estimate of maximal heart rate is not used in prediction, and replaced with individualized assessments of the heart rate responses to incremental exercise and recovery, improved accuracy of VO_2max prediction should result.

Therefore, given the importance of the prediction of VO_2max from submaximal exercise, and the fact that no precise method of VO_2max estimation exists, the primary purpose of this study was to develop an accurate and easy- to-use multiple regression equation to predict VO_2 max in men (< 40 yrs) and women (< 50 yrs) from an individualized submaximal cycle ergometer protocol. A secondary purpose of this study was to compare the accuracy of the new prediction equation with other commonly used prediction equations.

METHODS

Subjects

Forty-three males (18-39 yr) and thirty seven females (18-49) who were sedentary to highly trained volunteers were recruited from the student body of a large urban university and from the surrounding community. Before participating in the study, the subjects completed a health history questionnaire, and a consent form approved by the university's human subjects review board.

All subjects were non-smokers, apparently healthy and familiar with cycle ergometer exercise. Subjects were taking no medications and were free from cardiovascular and/or respiratory disease at the time of the study. Because of the maximal exertion required for the maximal cycle ergometer test, an age limit was imposed (male ≤ 39 years, female ≤ 49 years, all subjects > 18 years) based on the requirements of the university human subjects review board. Prior to reporting to the laboratory for the testing, subjects were given the following instructions: no eating, drinking (except water) within three hours, caffeine ingestion within twelve hours, and no heavy exercise within 18 hours prior to testing. All testing was performed at an altitude of 1540 meters and all subjects were residents of altitudes between 1350 – 1850 m for more than one year.

Table 4. Descriptive data for the sample with demographics, criterion, and predictor variables.

Variables	*Male n=43, Female n=37)*	
	Mean	*Range*
Age (years)	27.8±8.0	19-49
Height (cm)	172.1±9.1	152.7-197.3
Weight (kg)	70.4±13.7	51.3-113.3
Observed VO_2 max (ml/kg/min)	44.21±8.1	24.07-64.53
Body Fat (%)	20.62±8.4	3.75-43.02
Lo-PAR total (MET/hr/wk)	312.79±50.4	238.05-424.01
Lo-PAR exercise (MET/hr/wk)	70.77±43.9	0.50-207.0
HR rest (beats/min)	63.98±8.6	43-82
Predicted maximal HR (beats/min)	181.6±5.9	166.7-188.3
% 80 predicted maximal HR (beats/min)	145.6±4.6	133-151
SM2 minute watt increase (Watts/min)	25.3±6.8	15-45
SM2 exercise average HR (beats/min)	106.08±10.3	81-129
SM2 exercise HR/Time Linear Slope (value)	10.82±2.1	7.09-16.99
SM2 recovery ? HR(highest-lowest) (beats/min)	59.3±14.9	13-93
SM2 recovery HR/time non-linear K (value)	1.3377±0.52	0.4446-3.0520
SM2 recovery HR/time non-linear Half time (value)	.5897±0.24	0.1519-1.5590

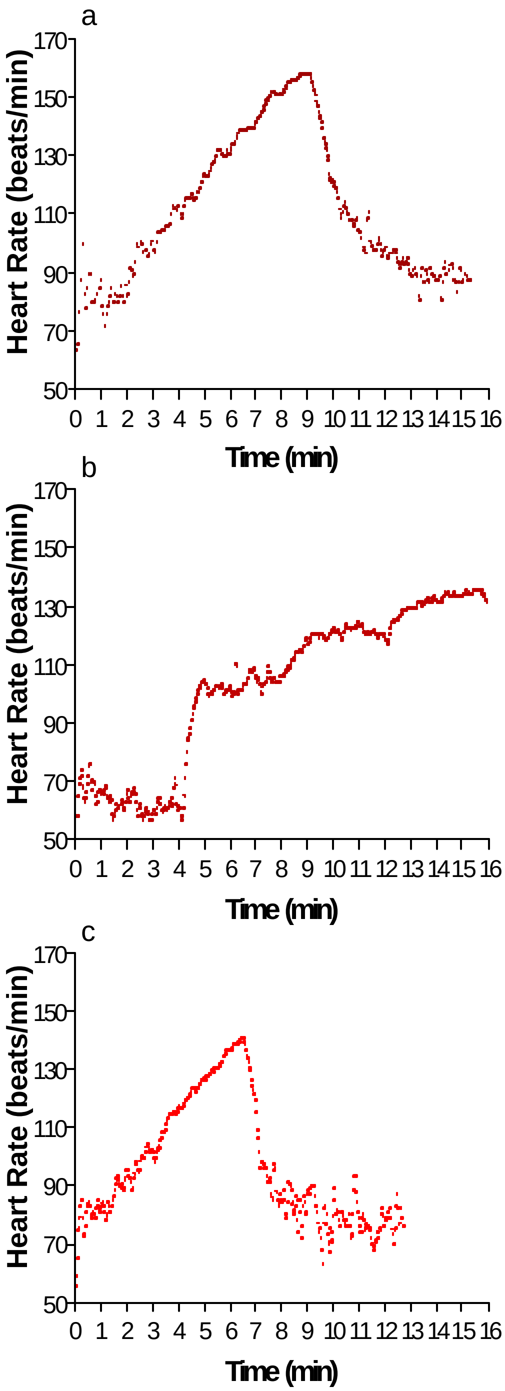

Figure 1. Examples of raw data from a representative subject for a) a ramp cycle ergometer to VO_2max and 6 min of recovery, b) the YMCA submaximal 4 min stage protocol, and c) an individualized ramp protocol to 80% predicted VO_2max.

Procedures

All questionnaires, health screening, anthropometric measurements, and physiological testing were completed in one session. When the participants reported to the laboratory, they were verbally informed of the procedures and possible discomforts and risks of the study. Following the completion of the medical history questionnaire, subjects were told if they were eligible to participate and were asked to read and sign an informed consent. After signing the consent, the Modified Physical Activity Recall Questionnaire (Lo-PAR) (30,31) was administered and completed by the participants. The total scores and exercise section scores of the Lo-PAR were recorded as predictor variables for subsequent statistical analysis.

After signing the consent, subjects were weighed in athletic apparel without shoes on a calibrated digital scale (Seca Corporation, Model # 707, Columbia, Maryland, USA) to the nearest 0.1 kg. Height measurements were obtained barefooted at mid-expiration and recorded to the nearest 0.5 cm using a stadiometer (Accu-Hite Stadiometer, Seca Corporation, Columbia, Maryland, USA). Skinfold thickness was measured to the nearest 0.5 mm using a Lange caliper (Cambridge Scientific Industries, Columbia, Maryland, USA). All measurements were taken on the right side of the body using anatomical sites according to the Jackson and Pollock (32,33) three-site equations for both men and women. Skin-fold measurements were performed until two were within 10% of each other. The equations developed by Heyward and Stolarczyk (34) were used to convert body density to % body fat for men and women.

Submaximal And Maximal Cycle Ergometer Tests

Each subject performed two submaximal and one maximal cycle ergometer tests using a Lode (Excalibur Sport, Corval Lode B.V., Lode Medical Technology, Groningen, Netherlands) constant-load (cadence independent) cycle ergometer. Initially, subjects rested for 5 minutes prior to the measurement of resting HR. Seat height and handlebars were adjusted to fit the subject prior to each test. HR and electrocardiogram readings for all tests were monitored and recorded continuously (Biopac, CA) using a 3-lead ECG configuration.

Submaximal Test 1- YMCA Test Protocol (SM1)

The original YMCA protocol (35) uses three or four consecutive 3-minute work loads. However, we modified the YMCA protocol to extend to 4-minute stages in order to more accurately detect steady state HR. Subjects performed cycler ergometry at a cadence of 50 rev/min, and the initial work load was 25 Watts. The heart rate during the last 15 seconds was used to determine subsequent work loads (if HR <80 beats/min:125 Watt; 80 to 90 beats/min:100 Watt; 90 to 100 beats/min:75 Watt; and >100 beats/min: 50 Watt). The test was terminated when two workloads were completed with heart rates between 110 and 150 beats/min. The subjects rested approximately 15 minutes before completing the second submaximal test.

Submaximal Test 2- Individualized 1-minute Step Cycle Ergometer Test Protocol (SM2)

After 15 minutes rest, when the subject's resting HR was within 5-10 beats/min of their recorded resting HR value, the second 1-minute step submaximal test was started. Subjects completed two minutes of warm-up cycling with no resistance. HR was obtained continuously. The workload was increased by 15-45 Watts/min based on the previous sub-maximal test's estimated VO_2max results. When subjects reached 80% of their age-predicted maximum heart rate ([202-0.72 x (age)] x .80) (36), the exercise intensity was decreased to 25 Watts and the subject continued to exercise for active recovery HR data collection.

Maximal cycle ergometer test

After 15-20 minute rest, when the subjects' resting HR reached about 5-10 beats/min of the initially recorded resting HR, the maximal cycle ergometer VO_2 test with expired gas analysis was started. The metabolic analyzers were calibrated prior to each test for every subject. For collection of VO_2 max data, an incremental ramp protocol using the same Watt/min increment from the previous step submaximal protocol. After measuring resting expired gases for 2 minutes, the protocol was started using a pedal rate of 70 rev/min. During the exercise test, VO_2, VCO_2, V_E, and respiratory exchange ratio (RER) were collected breath-by-breath using a fast response turbine flow transducer (K.L. Engineering Model S-430, Van Nuys, CA) and custom developed software (LabVIEW, National Instruments, Austn, TX) with AEI oxygen and carbon dioxide electronic gas analyzers (AEI Technologies, Model S-3A and Model CD-3H, Pittsburg, PA). Raw signals were acquired through a junction box connected to a PC computer and integrated with a data acquisition card (National Instruments, Austin, Texas). HR and electrocardiogram readings (Quinton 4000, Quinton, Seattle, WA) using a 3-lead ECG configuration were recorded continuously as a five-beat average via electronic integration by the custom developed hardware and software. VO_2 was considered maximal if the two of the following three criteria were achieved: 1) leveling of oxygen consumption despite an increase in work load; 2) respiratory exchange ratio (RER) = 1.1; and 3) HR within 15 beats of the age-predicted maximal HR.

Data Processing and Creation of Variables

From SM1

For the calculation of estimated VO_2max, HR was plotted against work (Watts) on a graph by drawing a line connecting the heart rates and extrapolating to the subject's age-predicted maximum heart rate [202-0.72 x (age) beats/min] (33) and followed by dropping a vertical line from the maximal heart rate to the x-axis. This point represented the estimated maximal power (Watts) at VO_2max. Then, the corresponding estimated VO_2max was calculated from watts using the following equation: VO_2max ($ml \cdot min^{-1}$) = (Watts x 6 kpm/Watt) x 2 ml/kpm +300 (32). In addition, estimated VO_2 max for ACSM and Astrand-Ryhming Nomogram were calculated for each subject from the YMCA's steady-state HR and workload data.

From SM2

In order to create an individualized protocol, the estimated Watt increases for every minute of the 1-minute step cycle ergometer test protocol were determined from the submaximal YMCA test (Equaton 1).

Watt Increase/min = [YMCA Estimated VO_2 max (L/min) x1000 / 11 mL/min/Watt[a]] / 12 min[b] + 5 Watt[c] Equation 1

The VO_2 Watt cost approximates 11 mL/min/Watt (37). For the VO_2max test to end within 10-12 minutes, we divided the peak Watts estimate by 12 to get a Watts/min ramp function. However, as incremental exercise has an increasing energy component from the phosphagen and glycolytic systems during the second half of the protocol, several pilot tests revealed the need to add 5 Watts to the final Watt/min ramp function. Submaximal exercise and recovery HR and workload data were used to determine the relationship between HR response and workload increase during exercise and recovery. Variables developed from this data included linear and non-linear regression slopes for HR and time, and recovery average and recovery delta (highest-lowest) HR (Prism, Graphpad Software, San Diego, CA).

From Maximal test

Maximal HR, VO_2, VCO_2, V_E, and respiratory exchange ratio (RER) were determined by averaging last 15 seconds of recorded data, centered around the peak breath-by-breath value.

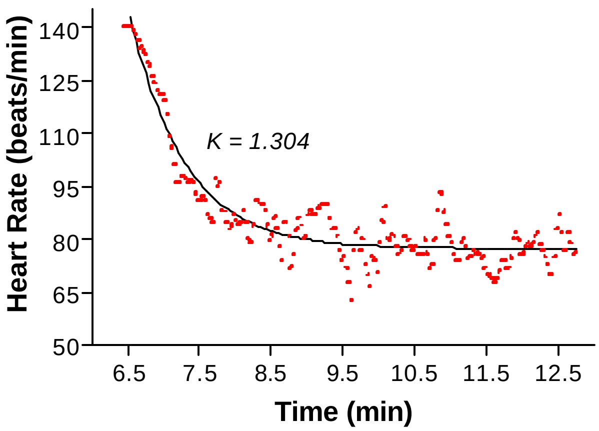

Figure 2. Recovery heart rate data for a representative subject after the STEP test.

Statistical Analyses

All data were analyzed using SPSS (Statistical Package for Social Sciences, version 11.1, Chicago, IL). Diagnostic tests were performed to detect missing, influential and/or outlying observations, of which none were found. In addition, all necessary data problem checking procedures were performed (distribution, normality, homogeneity, independence of error, linearity, and collinearity). Standard descriptive statistics (means, standard deviations, range) were used to present the characteristics of the subjects for all variables. The alpha level was set at $p<0.05$ for all analyses.

An hierarchical variable entry method was performed to obtain the best model for estimating relative (ml/kg/min) VO_2max. The variables initially used to select the best subsets were: age, gender (GND), height, weight (BW), % body fat (BF), Lo-PAR total score (LPTOT), Lo-PAR exercise score (LPEXER), heart rate rest (HHR), predicted maximal heart rate (PMHR), 80% predicted maximal heart rate (PRCHR), as well as step increment protocol's watt increase/min (MS2 WTIN), exercise average heart rate (MS2 EAHR), exercise heart rate vs time linear regression slope (MS2 LRSP), delta recovery heart rate (highest-lowest) (MS2 DRHR), and recovery heart rate vs time non-linear regression (one phase exponential decay) rate constant (MS2 RHRNK) and Half Time value (MS2 RHRNHT) (Prism, Graphpad Software, San Diego, CA). Generalized (gender-independent) and gender-specific equations were developed from the data to predict VO_2max. To determine the correlation and mean differences between actual and predicted VO_2 max, the Pearson Product Moment Correlation and Paired Sample t-test were also performed.

In addition, for the secondary purpose of this study, estimated VO_2 max was calculated for each subject from this investigation's new equations, YMCA, ACSM, and Astrand-Ryhming Nomogram. One-way analysis of variance (ANOVA) was used to determine if VO_2max predictions different between methods.

RESULTS

Raw Data

Examples of raw data from a representative subject for the heart rate responses for the three exercise and recovery tests are presented in Figure 1a-c. Figure 2 presents the method of modeling the recovery heart rate data for mono-exponential curve fitting to derive the rate constant variables.

Gender-specific equations developed from the data did not explain more variance than the generalized equation, so subsequent discussion will include only the gender- independent equation. Table 2 presents the means, standard deviations, and ranges for the demographic characteristics of the sample as well as the criterion and all independent (predictor) variables used in the multiple regression procedure.

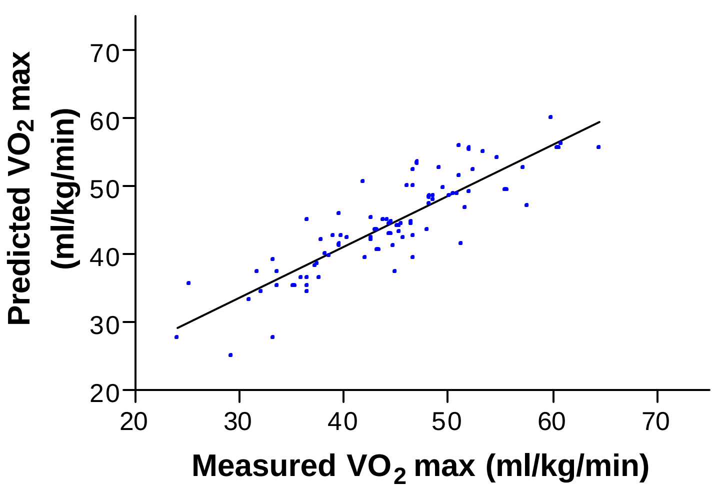

Figure 3. The relationship between measured VO_2max and predicted VO_2max using the multiple regression equation as presented in the text

Regression Equation Derived From The Sample

A two-step regression procedure was applied to obtain the best model for the prediction equation. For the first step, all predictor variables were entered simultaneously into the model to evaluate their unique contribution to the overall regression model and to the observed VO_2max. Using all predictor variables, this regression model resulted in an R^2 = 0.761, an adjusted R^2 = 0.700, and standard error of the estimate (SEE) = 4.47 ($ml \cdot kg^{-1} \cdot min^{-1}$). The Durbin-Watson test was also calculated to evaluate if the independence of error assumption in the regression model was met. The value was 2.30, which indicated that this assumption was met. The standardized ß indicates the magnitude of the unique contribution that each predictor variable makes to maximally predicting the observed VO_2max in the regression model. Only five variables (SM2 Watt/minute increase, weight, gender, SM2 recovery delta HR, and SM2 recovery HR non-linear K value) made a significant contribution to the prediction model according to the t values for each ß coefficient.

For the second step, an hierarchical multiple regression variable entry method was used by entering all four previously determined significant variables as the first block of variables and then entering other non-significant variables block by block into the regression model. Several regression equations were obtained to predict VO_2 max, and from those, the most efficient prediction model was selected. This equation was the one that required the least time to complete and the fewest variables to monitor, yet retained accurate estimates of VO_2max with a low SEE (<5 ml/kg/min). The model summary, set of predictor variables, and inter-correlations among predictor variables as well as the observed VO_2 max from the selected best model are presented in Tables 5-7. The prediction equation derived from the data was as follows:

$$\mathbf{VO_2\ max}\ (\text{ml/kg/min}) = 46.103 + (-0.353BW) + (0.683\ MS2\ WTIN) + (-5.995\ GND^{a}) + (0.165\ MS2\ DRHR) + (2.816\ MS2\ RHRNK) + (0.0138\ LPEXER) + 4.234$$

a. Coded as Male=1 Female=2

Table 5. The model summary of the hierarchical regression procedure.

Model	*R*	R^2	Adj. R^2	*SEE*	*F Change*	*Sig. F Change*	***Durbin-Watson***
1	.867[a]	.751	.731	4.234	36.774	.000	2.304

a. Predictors: (constant), SM2 minute watt increase, weight, gender, SM2 recovery delta HR, SM2 recovery HR/time non-linear K value, Lo-PAR Exercise score
b. Dependent variable: Measured VO_2max

Table 6. Set of predicted variables from regression procedure.

Predictors	*B*	*ß[a]*	*t*	*?*
(Constant)	46.103	-	9.181	.001
Weight	-0.353	-0.595	-7.499	.001
SM2 minute watt increase	0.683	0.570	6.658	.001
Gender	-5.995	-0.386	-4.760	.001
SM2 recovery ? HR(highest-lowest)	0.165	0.302	4.505	.001
SM2 recovery HR/time non-linear K value	2.816	0.182	2.905	.005
Lo-PAR exercise	0.0137	0.074	1.129	.263

a. Dependent Variable: Measured VO_2max

Table 7. Inter-correlations among predictor variables and the observed VO_2max.

	Predictor	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	**Observed VO_2max**	1.000	-0.105	0.563	-0.369	0.607	0.095	0.417
2	**Weight**		1.000	0.550	-0.533	0.046	-0.231	0.110
3	**SM2 minute watt increase**			1.000	-0.506	0.421	-0.122	0.399
4	**Gender**				1.000	-0.234	0.348	-0.311
5	**SM2 recovery ? HR(highest-lowest)**					1.000	-0.073	0.263
6	**SM2 recovery HR/time non-linear K value**						1.000	-0.072
7	**Lo-PAR exercise**							1.000

There was a significant correlation between actual and predicted VO_2max (r= .867, p< 0.0001), and paired sample statistics showed no statistically significant difference between measured and predicted VO_2max. (t=1.156, SD=4.07, p=0.99). Predicted versus measured VO_2max values are plotted in Figure 3.

Comparisons Of Commonly Used Prediction Equations

One-way analysis of variance (ANOVA) was used to determine the mean differences between the study results for the YMCA, the ACSM, and the Astrand-Ryhming Nomogram's estimated VO_2 max, and the actual measured VO_2 max. Means, standard deviations, and ranges for all four estimation equations and observed VO_2 max are presented in Table 8. One-way analysis of variance showed a significant ($p<0.0001$) difference in the actual VO_2 max and estimated VO_2 max from the YMCA equation, the ACSM equations, and the Astrand-Ryhming Nomogram. However, the mean difference between this study's equation's estimated VO_2 max and observed VO_2 max was not significant. ($F_{(4,395)} = 13.12$, MSE=68.7, p=0.97, N=80). Results also showed that YMCA, ACSM, and Astrand-Ryhming Nomogram underestimated true VO_2 max. ANOVA results and Tukey HSD multiple comparisons are presented in Table 9 and 10. Means of predicted and measured VO_2 max scores were plotted in Figure 4.

Table 6. Means, standard deviations, and ranges for all four estimation equations and observed VO_2 max.

	(N=80)		
	Mean	SD	Range
Observed VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.22	8.1	24.07-64.53
YMCA Equation	38.77	8.9	17.91-57.20
ACSM Equation	36.88	8.6	17.61-56.77
Astrand-Rhyming Nomogram	40.05	8.4	21.58-59.85
Study's new equation	44.20	7.1	25.20-60.07

Table 7. ANOVA results (N=80).

Mean	*Sum of Squeres*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	3609.129	4	902.282	13.126	<.001*
Within Groups	27153.339	395	68.743		
Total	30762.468	399			

p< 0.05

Table 8. Tukey HSD Multiple comparisons between new equation,s, the YMCA's, the ACSM's, and the Astrand-Ryhming Nomogram's estimated, and the actual measured VO_2max.

(N=80)		*Mean diff.*	*Standard Error*	*Sig*
Observed VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)		--		
	YMCA equation	5.84	1.31	<.001*
	ACSM Equation	7.33	1.31	<.001*
	Astrand-Rhyming Nomogram	4.16	1.31	<.001*
	Study's new equation	.002	1.31	1.000

* p< 0.05

DISCUSSION

Maximal oxygen uptake can be predicted with reasonable precision (R=0.867, SEE=4.23 ml/kg/min) from individualized submaximal cycle ergometer test data using multiple regression equations. Lewis et al. (38) showed that variations in VO_2max with different forms of exercise generally reflect the quantity of muscle mass activated. Studies that determined VO_2max for the same subjects during different exercise modes indicate that treadmill exercise usually produces the highest values

(39).Treadmill exercise proves highly desirable for determining VO_2max in healthy subjects in the laboratory. Most studies show that VO_2max measured on a cycle ergometer is 10% to 15% less than that measured on a treadmill (40). Swain and Wright (41) found that cadences between 50 and 80 rev/min were equally valid for predicting VO_2max from submaximal cycle ergometer. We selected 70 rpm as a conservative median value to use for this study.

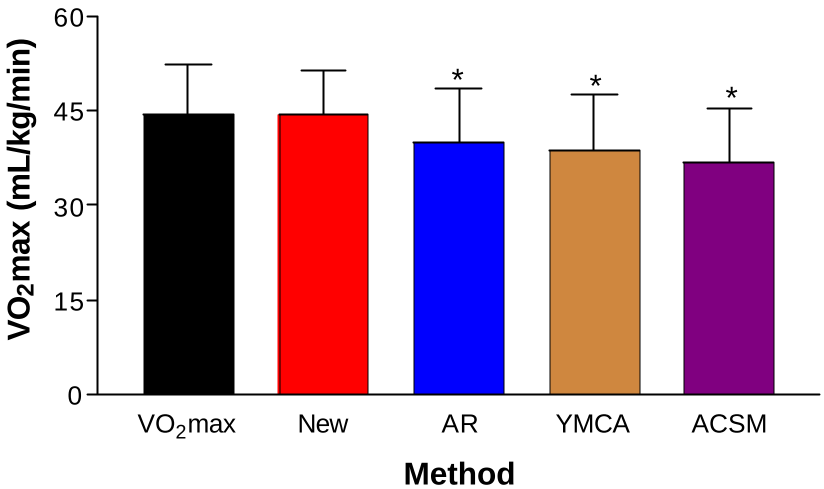

Figure 4. Mean±SD data for VO_2max that was measured and predicted from the different methods identified in text. VO_2max=as measured in this study; YMCA=YMCA equation; ACSM=ACSM equation; AR=Astrand-Rhyming nomogram; New=from prediction equation of this study. *= different ($p<0.05$) from measured.

Studies in which advantages and disadvantages of various exercise modes and protocols have been discussed reported that an ideal protocol should consider the following: 1) the purpose of the test; and 2) the subject tested (42). For most exercise tests, however, the choice of protocol is directed by tradition, equipment, or convenience. The need to maintain a test duration of 12 minutes suggests that increments in intensity will be different for individuals of differing cardiorespiratory fitness. This fact stresses the need to tailor a protocol to suit a given individual. Therefore estimation of a person's cardiorespiratory fitness, habitual physical activity level, and training history are important first steps in determining a protocol for testing. This estimation can then be applied to different testing procedures (29)

This study employed a modified physical activity questionnaire called Lo-PAR to estimate habitual exercise level of the subjects. The Lo-PAR exercise score was used in the regression model to predict VO_2max and it was one of the most meaningfull predictor variables that contributed to the exploration of between subject variance in VO_2max.

Declining physical activity appears to be a major factor, along with the loss in fat-free mass and increase in fat mass, in describing the decline in VO_2max in adult and older persons (43). In addition, prolonged inactivity has many detrimental effects on the skeletal muscles and the cardiovascular system. For example, bed rest leads to a decrease in VO_2max of 0.8% per day (44). Research has shown that the rise in aerobic power with training is just as rapid as its fall without it, and most of the improvements in VO_2max occur within three weeks of beginning intense (3-4 times a week, moderate to high intensity) cardiorespiratory training. In addition, once the desired VO_2max is achieved, it is possible to maintain it by reducing the frequency and maintaining the intensity of training (45). Based on this information concerning effects of training and high level of physical activity, it is not surprising that Lo-PAR exercise was selected as an important predictor variable in the current study's equation.

One obvious shortcoming of the approach described in this study was the use of two tests instead of one. The first test (SM1) was performed for one purpose: to estimate subject's peak Watts at the level of maximal oxygen consumption through an easy-to-use cycle ergometer protocol and therefore, to evaluate how accurately a targated test duration and intensity could be attained using the individualized approach. The minute Watt increase which is individually determined for every subject in this study was identified as a significant predictor by the regression model to predict of VO_2max.

Gender-specific equations developed from the data (R=.843, SEE 4.87 for male, and R=.835, SEE 5.54 for female) did not explain more variance than the generalized equation, so subsequent discussion will include only the gender independent equation. The lower explained variance and higher SEE from the gender-specific regression model most likely due to the smaller sample size (male 43, female 37).

While the absolute VO_2 (L/min) for treadmill exercise at any given work rate is substantially affected by body weight, such is not the case in cycle ergometer exercise since the body weight is supported by the seat. However, Wasserman and Whipp (46) have reported that VO_2 is influenced by the subject's body weight even in the weight-supported cycle exercise due to the differences in the O_2 cost of moving large leg muscles; for any given work rate, they found that VO_2 was 5.8 mL/min higher for each additional kilogram of body weight. It can be clearly seen from Table 1 that body weight and gender are significant predictor variables in other studies. This is true in the present investigation. The most striking difference between the regression equation generated from the present data set and previously reported regression equations is the inclusion of subject's recovery HR response as a significant predictor of VO_2 max. As presented in Table 1, only McArdle's and Jette's gender-specific prediction equations uses the recovery heart rate as a predictor variable in the equation. McArdle clearly stated that their step test recovery HR provided significant information about VO_2max. They found that subjects with high recovery HR and a slow decrease pattern tended to have a lower VO_2 max whereas a faster recovery (faster reduction, lower HR) related to relatively high VO_2 max values. Similarly recovery delta (highest-lowest) HR and recovery HR/Time non-linear (one phase exponential) statistics K value from this study were selected as important predictor variables in the regression model.

Age was not an important predictor in our regression model. Functional capacity of an individual declines after the age of 30 yrs, with deterioration varying at any age depending on various conditions, especially lifestyle characteristics (39). The subject's mean age was 27.8 and Lo-PAR scores indicated that 95 % of the subjects were inactive to very active (>250 MET/hr/week) with only 5% were in the less active category. Having young subjects who have active to very active lifestyles may be the underlying reason for this result.

The Astrand-Ryhming Nomogram (47) assumes a linear relationship between heart rate (HR) and oxygen consumption. Based on this assumption, an extrapolation of the HR response to a submaximal workload on a cycle ergometer is used to estimate VO_2max. Glassford et al. (48) and Teraslinna et al. (49) used an age-correction factor in conjunction with the nomogram and found a correlation between measured and estimated VO_2 max of 0.92 and 0.80, respectively. Davies (1) showed that the Astrand-Rhyming Nomogram consistently underestimated VO_2max.

In the 4th edition of its Guidelines text, the ACSM submaximal bicycle test (50) consisted of multiple (generally 3 or 4) two-minute stages designed to have the subject approach a heart rate of 70% of age predicted maximum. In its 5th edition Guidelines, the ACSM modified its bike test protocol to make the stages 3 minutes in length. Swain and Wright (41) evaluated this test and found that this method also overestimated the actual VO_2max by 28% on average. They concluded that the length of the stages in the ACSM protocol may be the principal reason for the overestimation of VO_2max. If higher HR were obtained for a given workloads, the extrapolated values of estimated maximal workload and estimated VO_2max would be lower, and thus, might not be overestimated.

A similar test commonly used for fitness screening is the submaximal cycle ergometer test outlined by the YMCA, in which work is incremented based on the HR response to a submaximal level (32). Although the HR response to any given workload has been shown to roughly reflect the physical working capacity of an individual, there are limitations associated with the use of HR as a single independent variable to estimate VO_2max. Another problem with these methods is the assumption required for a target maximal HR using age as the only predictor variable. Many laboratories report standard deviations for age-predicted maximal HR in the order of 10-15 beats/min (2).

Tables 1, 2 and 3 contain summaries of predictor variables, correlation coefficients, and SEE of most prior research of VO_2max prediction equations. When several equations were presented by other studies, the equation which yielded the highest R and the lowest SEE was selected for comparisons. It is apparent from these tables that the multiple regression equation derived from this study with a 0.867 R value, 75% explained variance, and 4.234 (mL/kg/min), and 0.29 (L/min) SEE is more accurate than most of the other prediction equations, especially those using nomograms as a prediction tool.

The primary reason for the greater accuracy of the prediction found in this study is likely due to the individulized submaximal protocol approach. In this approach, SM1 was used to determine the best watt increment for the SM2 and the use of 4-minute stages rather than 3-min stages may have allowed the subject to reach a true steady-state HR. If a steady-state HR is not achieved at submaximal stages of SM1 of YMCA protocol, then the recorded HR will be low, resulting in an overprediction of the workload. Therefore, it was expected that the longer stage length used in SM1 would (and did) result in greater accuracy in minute watt increase in SM2 protocol and therefore a significantly higher contribution to VO_2max prediction from SM2 data. Under these circumstances, it is not surprizing that the mean difference between the YMCA's, the ACSM's, and the Astrand-Ryhming Nomogram's estimated VO_2max and observed VO_2max were significant, whereas the mean difference between this study's equation's estimated VO_2max and observed VO_2max was not significant (Table 8, Figure 4).

CONCLUSIONS

The use of multiple regressions with a hierarchical variable entry method proved to be an effective method of developing a satisfactory submaximal cycle ergometer prediction equation. The technique of this multiple regression allows the inclusion of additional determinants of VO_2max if more precise estimate is required.

Equations such as the one presented in this study should be tested on multiple populations to discern its validity in these special populations. The application of the equation and methods of testing used in this study to include individuals in clinical settings may enhance and expand it's utility as a valuable tool for classifying exercise capacity and exercise prescription in a broad range of individuals.

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