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Estimation of $\dot{V}O_{2max}$ from a one-mile track walk, gender, age, and body weight

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ABSTRACT

KLINE, G. M., J. P. PORCARI, R. HINTERMEISTER, P. S. FREEDSON, A. WARD, R. F. MCCARRON, J. ROSS, and J. M. RIPPE. Estimation of $\dot{V}O_{2max}$ from a one-mile track walk, gender, age, and body weight. *Med. Sci. Sports Exerc.*, Vol. 19, No. 3, pp. 253-259, 1987. The purpose of this investigation was to explore an alternative field test to estimate maximal oxygen consumption ($\dot{V}O_{2max}$) using a one-mile walk test. $\dot{V}O_{2max}$ was determined in 343 healthy adult (males = 165, females = 178) subjects 30 to 69 yr using a treadmill protocol (mean ± SD: $\dot{V}O_{2max}$ = 37.0 ± 10.7 ml·kg^{-1}·min^{-1}). Each subject performed a minimum of two, one-mile track walks as fast as possible. The two fastest walks (T1, T2) with elapsed times within 30 s were used for subsequent analyses. Heart rates were monitored continuously and recorded every one-quarter mile. Multiple regression analysis (best sub-sets) to estimate $\dot{V}O_{2max}$ (l·min^{-1}) yielded the following predictor variables: tract walk-1 time (T1); fourth quarter heart rate for track walk-1 (HR1-4); age (yr); weight (lb); and sex (1 = male, 0 = female). The best equation (N = 174) was:

$$\dot{V}O_{2max} = 6.9652 + (0.0091 \cdot WT) - (0.0257 \cdot AGE) + (0.5955 \cdot SEX) - (0.2240 \cdot T1) - (0.0115 \cdot HR1\text{-}4);$$
$$r = 0.93, \quad SEE = 0.325\ l \cdot min^{-1}.$$

Comparing observed and estimated $\dot{V}O_{2max}$ values in a cross-validation group (N = 169) resulted in r = 0.92, SEE = 0.355 l·min^{-1}. Generalized and sex-specific equations to estimate $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) were also generated. The accuracy of estimation as expressed by SEE was similar among the equations. The results indicate that this one-mile walk test protocol provides a valid sub-maximum assessment for $\dot{V}O_{2max}$ estimation

WALKING, HEART RATE, $\dot{V}O_{2max}$ ESTIMATION, FIELD TEST, AEROBIC POWER

The direct measurement of maximal oxygen consumption ($\dot{V}O_{2max}$) is considered the most accurate method of assessing an individual's aerobic capacity. Direct measurement, however, is expensive, time-consuming, requires high subject motivation, and does not lend itself to testing large numbers of subjects. These limitations were recognized as early as the 1920's by members of the Harvard Fatigue Laboratory, who attempted to develop a sub-maximal test to classify individual fitness levels. Their first attempt, "the stone boat test," involved dragging a weighted sled 300 yards, and measuring recovery heart rate (HR) (13). Later attempts in their laboratory evolved into the well-known Harvard Step Test. Currently, a multitude of sub-maximal protocols exist, each designed to estimate $\dot{V}O_{2max}$ or simply categorize an individual's aerobic fitness level. These methods commonly employ bench stepping, bicycle ergometry, walking/running, or treadmill exercise. Table 1 summarizes a variety of tests that have been used to estimate $\dot{V}O_{2max}$.

A popular field test to estimate $\dot{V}O_{2max}$ was developed by Cooper (4) in 115 men (17 to 52 yr) and was based on the finding that the distance covered (walking/running) in 12 min was correlated to maximum aerobic capacity (r = 0.90). However, as Jackson and Coleman (14) pointed out, tests valid and reliable on one population may or may not be valid and reliable on other populations. Thus, attempts to validate this field test on more homogeneous and/or different populations have yielded correlations ranging from r = 0.13 to r = 0.90 (3, 7, 15, 18, 21).

The popular Åstrand-Ryhming Nomogram (1) is based on an assumed linear relationship between (HR) and oxygen consumption, where HR response to a sub-maximal workload on the bicycle ergometer is used to estimate $\dot{V}O_{2max}$. Davies (5), however, noted that $\dot{V}O_{2max}$ is consistently under-estimated due to the asymptotic pattern of HR response as one approaches $\dot{V}O_{2max}$. Several studies have attempted to cross-validate this nomogram. Using the age-correction factor, Teraslinna et al. (30) and Glassford et al. (11) reported correlations of r = 0.92 and r = 0.80, respectively, between measured and estimated $\dot{V}O_{2max}$. DeVries and Klafs (6) present a validity coefficient of r = 0.74 in 16 males (20 to 26 yr). Lower correlations (r = 0.47 and r = 0.64) have been reported by Hermiston and Faulkner (12) in 28 men (25 to 45 yr) and Jessup et al. (15) in 40 male volunteers (18 to 23 yr).

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TABLE 1. Summary of $\dot{V}O_{2max}$ prediction tests.

Type	Study	*N*	Age (yr)	Sex	$\dot{V}O_{2max}$ (l·min⁻¹ ml·kg⁻¹·min⁻¹)	Predictor Variables	R	SEE (l·min⁻¹ ml·kg⁻¹·min⁻¹)
Bench	McArdle et al. (23)	41	18–22	F	2.16–2.70 37.1–45.7	Recovery HR	0.75	— 2.9
	Jette et al. (16)	24 35	15–74	F M	36.0 ± 10.4	Age, weight, $\dot{V}O_2$, recovery HR	—	4.1
Cycle ergometer	Fox (9)	87	17–27	M	2.32–4.29 27.9–55.5	5th min HR at 900 kpm	0.76	0.246
	Åstrand and Ryhming (1)	27 31	18–30	M F	4.10 2.87	(M) HR: 900 kpm 1200 kpm (F) HR: 600 kpm 900 kpm	— — — —	0.43 0.28 0.42 0.27
	Mastrapaolo (22)	13	43–61	M	2.62 ± 0.37	RER, DBP, $\dot{V}_E$, F_eO_2, work (kpm)	0.93	0.172
	Siconolfi et al. (28)	63 25 28	20–70	M/F M F	2.07 ± 0.74 2.54 ± 0.59 1.48 ± 0.41	Age, $\dot{V}O_2$, predicted from Åstrand-Ryhming	0.94 0.86 0.97	0.248 0.359 0.199
Treadmill	Bonen et al. (2)	100	7–15	M	1.78 ± 0.52 32.1 ± 2.8	HR, $\dot{V}CO_2$, $\dot{V}O_2$, age	0.95 0.62	0.170 4.1
	Metz and Alexander (25)	60	12–13 14–15	M M	2.55 ± 0.56 50.9 3.09 ± 0.44 53.3	HR, $\dot{V}O_2$, RER	0.70 0.48	— 3.8 3.57
	Hermiston and Faulkner (12)	28	25–45	M	3.1 ± 0.70	Age, FFW, HR, F_eCO_2, V_T, RER	0.90	—
Track—run/walk	Cooper (4)	115	17–52	M	—	12-min run/walk distance	0.90	—
	Doolittle and Bigbee (7)	9	14–15	M	—	12-min run/walk distance	0.90	—
	Getchell et al. (10)	21	18–25	F	2.61 ± 0.44 46.2 ± 5.9	1.5-mile run time	0.46 0.91	— —
	Ribisl and Kachadorian (26)	24 11	30–48 18–22	M M	48.5 ± 4.9 57.3 ± 3.6	Age, weight, 100 yards, 200 yards, 2-mile run time	0.95 0.94	1.97 1.55
	Present study	343	30–69	M F	3.35 ± 0.72 1.99 - 0.49	1-mile walk time, age, HR 1–4, weight	0.93	0.325
Others	Jessup et al. (15)	40	18–23	M	3.39 ± 0.40 48.9 ± 7.6	DBP, leg length, 12-min run/walk distance; $\dot{V}O_2$ predicted from Åstrand-Ryhming	0.81 0.69	0.188 2.7
	Falls et al. (8)	87	23–58	M	3.13 ± 0.54 39.5 ± 7.6	AAHPERD Fitness Test: pull-ups, 50-yard dash, shuttle run	0.54 0.76	— 4.7
	DeVries and Klafs (6) (validation of several tests)	16	20–26	M	3.81 ± 5.3 50.5 ± 9.9	Sjöstrand; Harvard Step; Progressive HR; Åstrand-Ryhming	0.87 0.76 0.71 0.74	4.7 6.3 6.9 0.36

The abbreviations used are: $\dot{V}O_2$ = oxygen consumption; FFW = fat-free weight; $\dot{V}_E$ = minute ventilation; V_T = tidal volume; DBP = diastolic blood pressure.

Bench stepping has become a popular protocol for rapidly testing large numbers of subjects. The original Harvard Step Test was validated by DeVries and Klafs (6) who reported a correlation of $r = 0.76$ between recovery HR and $\dot{V}O_{2max}$. The Harvard Step Test was later modified into the Queen's College Step Test by McArdle et al. (23), who found a correlation of $r = 0.75$ between recovery HR and $\dot{V}O_{2max}$ (SEE = 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$) in 40 college-aged women. In an attempt to validate several existing bench-stepping protocols, Johnson and Siegel (17) tested 34 female college students and reported correlations ranging from $r = 0.42$ to $r = 0.62$ for six different step tests.

Of the numerous predictive tests reported in the literature, most do not present cross-validation results (8, 9, 16, 22, 26), many were developed on age/sex-specific populations (2, 9, 15, 21–23, 25), several require sophisticated laboratory equipment (2, 9, 12, 22, 25), and many provide no measure of the SEE (4, 7, 10, 12, 21), which describes the accuracy of predicting an individual's $\dot{V}O_{2max}$. As a result, the practical utility of these sub-maximal protocols may be questioned on the basis of three main considerations: i) accuracy and validity of the prediction; ii) ease and convenience of the testing protocol; and iii) generalized application to a broad population.

In an attempt to avoid these limitations, the current study sought to develop a sub-maximal field test for estimating $\dot{V}O_{2max}$ using a one-mile walk as the exercise test. The study population included a broad age range (30 to 69 yr) of males and females who were heterogeneous in $\dot{V}O_{2max}$. Moreover, all derived equations were cross-validated.

METHODS

Subjects. The subjects included 390 (males = 183, females = 207) healthy volunteers aged 30 to 69 yr. Each subject completed a brief medical questionnaire designed to screen for cardiovascular and orthopedic contraindications to brisk walking. None of the subjects were on any medication known to affect HR or blood pressure response to exercise. All subjects over the age of 40 yr were examined by a cardiologist, who was also present for the maximal treadmill test. Informed consent documents were signed by all participants in accordance with University of Massachusetts Medical School Guidelines.

Testing procedures. Each subject was weighed and prepared for ECG monitoring (standard limb leads) prior to testing. $\dot{V}O_{2max}$ was determined using a treadmill protocol consisting of walking or running at a self-selected speed, with a 2.5% increase in grade every 2 min. The test was terminated when the subject could no longer continue despite verbal encouragement. Expired gases were collected and analyzed by the SensorMedics Horizon metabolic cart (SensorMedics, Anaheim, CA) every 30 s. HR was determined by ECG and also recorded every 30 s.

Oxygen consumption was considered maximal if two of the following three criteria were achieved: i) leveling off of oxygen consumption despite an increase in work (29); ii) respiratory exchange ratio (RER) ≥ 1.1; and iii) HR no less than 15 beats below age-predicted maximal HR. Of the original 390 subjects, 343 (males = 165, females = 178) fulfilled at least two of the three necessary criteria and were included in the final analyses. Descriptive statistics for these subjects are presented in Table 2.

In addition, each subject performed a minimum of two, one-mile walks on a measured track. Subjects were instructed to walk as fast as possible. If times for the first two walks were not within 30 s of each other, subsequent walks were performed until this criterion was met.

Walks were performed on separate days, to eliminate any possible fatigue effects. The two walks (T1, T2) with elapsed time within 30 s were used for analysis. HR was monitored and recorded every minute during the walk with the AMF Quantum monitoring system (AMF Corporation, White Plains, NY). The mean of the last two 1-min HRs at the end of each one-quarter mile segment for track walk 1 and track walk 2 was calculated. Thus, four HR values for each walk were entered into the regression analysis. The AMF system was validated on 10 subjects (a total of 100 HR measurements ranging from 75 to 175 bpm). Of the 100 measurements, 66 were identical with simultaneous ECG monitoring. The remaining 34 measurements were within 3 bpm of the ECG.

Statistical analysis. The 343 subjects were assigned to either a validation (V) ($N = 174$) or cross-validation (CV) ($N = 169$) group on the basis of odd-even case selection. The data from the V group were used to develop equations for estimating $\dot{V}O_{2max}$ ($l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$) using "best subsets" multiple regression analysis (BMDP). The variables initially used to select the best subset were the following: age; weight; height; sex; and quarter mile HRs and total elapsed time for each one-mile walk. Generalized equations in $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ were developed as well as sex-specific equations. These equations were then cross-validated on the CV group using Pearson product moment correlations, SEE, and paired Student's t-tests to compare observed and estimated $\dot{V}O_{2max}$.

RESULTS

Descriptive statistics for the V and CV groups are presented in Table 2. Student's t-test analyses indicated

TABLE 2. Descriptive characteristics of the V and CV groups.

Group	N	Age (yr)	Height (cm)	Weight (kg)	HR_{max} (bpm)	$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR 1-4* (bpm)	T1† (min)
30–39									
V	46	33.9 ± 3.0	169.5 ± 7.8	70.5 ± 14.2	187 ± 7	3.00 ± 0.77	43.3 ± 9.7	145 ± 22	13.56 ± 1.24
CV	48	33.9 ± 3.1	169.6 ± 10.5	71.6 ± 15.2	186 ± 8	3.21 ± 0.97	44.8 ± 9.6	146 ± 20	13.46 ± 1.10
40–49									
V	49	43.6 ± 2.9	169.6 ± 11.2	73.1 ± 13.6	183 ± 11	2.94 ± 1.01	39.8 ± 10.0	145 ± 23	13.89 ± 2.08
CV	50	43.2 ± 2.8	169.0 ± 10.4	71.7 ± 16.3	181 ± 10	2.77 ± 0.87	38.8 ± 9.5	143 ± 21	13.94 ± 1.46
50–59									
V	45	53.8 ± 2.9	167.7 ± 9.8	76.0 ± 13.0	174 ± 11	2.46 ± 0.75	32.3 ± 8.1	143 ± 19	14.48 ± 1.80
CV	35	54.6 ± 2.4	167.2 ± 10.5	70.0 ± 14.4	172 ± 9	2.30 ± 0.72	32.9 ± 7.9	142 ± 23	14.41 ± 1.72
60–69									
V	34	63.6 ± 2.7	164.7 ± 7.4	67.6 ± 9.3	164 ± 13	1.89 ± 0.55	27.9 ± 7.0	142 ± 16	14.92 ± 1.68
CV	36	64.4 ± 2.5	166.4 ± 10.9	72.6 ± 15.0	165 ± 10	2.14 ± 0.73	29.2 ± 6.5	141 ± 21	14.84 ± 1.38
Overall									
V	174	47.6 ± 11.1	168.1 ± 9.4	72.0 ± 13.1	178 ± 13	2.62 ± 0.90	36.5 ± 10.6	144 ± 20	14.16 ± 1.79
CV	169	47.4 ± 11.8	168.2 ± 10.5	71.5 ± 15.2	177 ± 12	2.66 ± 0.94	37.2 ± 10.4	143 ± 21	14.09 ± 1.49
Males									
V	82	46.5 ± 10.7	175.4 ± 6.7	79.2 ± 11.3	178 ± 13	3.31 ± 0.71	42.2 ± 9.8	141 ± 22	13.30 ± 1.35
CV	83	46.4 ± 11.9	176.5 ± 7.1	81.5 ± 12.8	177 ± 12	3.40 ± 0.73	42.4 ± 10.5	137 ± 22	13.42 ± 1.28
Females									
V	92	48.5 ± 11.4	160.2 ± 6.2	65.4 ± 11.0	176 ± 14	2.01 ± 0.54	31.4 ± 8.5	146 ± 18	14.90 ± 1.80
CV	86	48.3 ± 11.6	161.7 ± 6.3	61.8 ± 10.4	177 ± 12	1.95 ± 0.43	32.2 ± 7.5	149 ± 18	14.70 ± 1.37

* HR 1-4 = HR at the end of the last one-quarter mile for walk one.
† T1 = time for walk one expressed as minutes.

no significant differences between the V and CV groups for any of the independent variables. The validity group reliability data for the last quarter-mile HRs (HR1-4, HR2-4) and total elapsed time (T1, T2) for track walks 1 and 2 were: HR (r = 0.93, SEE = 7.6 bpm) and time (r = 0.98, SEE = 0.26 min).

Regression equations derived from V group. The correlation matrices for the variables selected by the best subsets regression analysis for use in the generalized and sex-specific equations are presented in Table 3. The generalized and sex-specific multiple regression equations in $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ are presented in Table 4. The multiple correlations ranged from 0.86 to 0.93 for the $l \cdot min^{-1}$ equations with standard errors that varied from 0.249 to 0.358 $l \cdot min^{-1}$. For the $ml \cdot kg^{-1} \cdot min^{-1}$ equations, multiple correlations ranged from 0.85 to 0.88, with standard errors ranging from 4.5 to 5.0 $ml \cdot kg^{-1} \cdot min^{-1}$.

Cross-validation of the generalized equation in $l \cdot min^{-1}$ on the total CV group ($N = 169$) resulted in r = 0.92 and SEE = 0.335 $l \cdot min^{-1}$ (Figure 1 and Table 5). In addition, no differences between observed (2.66 ± 0.94 $l \cdot min^{-1}$) and estimated (2.67 ± 0.87 $l \cdot min^{-1}$) mean $\dot{V}O_{2max}$ values were found. When the generalized equation in $l \cdot min^{-1}$ was cross-validated by decade (e.g., 30 to 39 yr, 40 to 49 yr), no significant differences existed between the observed and estimated $\dot{V}O_{2max}$ values. Correlations ranged from r = 0.89 to r = 0.93, and the SEEs ranged from ±0.278 to 0.356 $l \cdot min^{-1}$. When the generalized equation was used to estimate $\dot{V}O_{2max}$ for the CV group male and females separately, the SEEs were 0.277 and 0.249 $l \cdot min^{-1}$, respectively.

The correlations and SEEs for the male and female equations in $l \cdot min^{-1}$ were r = 0.82 and r = 0.83 and 0.324 and 0.209 $l \cdot min^{-1}$, respectively. No differences between observed and estimated mean $\dot{V}O_{2max}$ values were found for males or females using the sex-specific equations (Table 5).

Cross-validation of the generalized equation in $ml \cdot$

TABLE 3. Correlation matrix of predictor variables.

	Age	Sex	Weight	T1	HR 1-4
Generalized					
Sex	−0.09				
Weight (lb)	−0.06	0.54			
T1 (min)	0.29	−0.47	−0.11		
HR 1-4 (bpm)	−0.07	−0.10	−0.04	−0.36	
$\dot{V}O_2$ ($l \cdot min^{-1}$)	−0.48	0.75	0.54	−0.64	−0.14
Males					
Weight (lb)	−0.05				
T1 (min)	0.37		0.27		
HR 1-4 (bpm)	0.14		0.14	−0.49	
$\dot{V}O_2$ ($l \cdot min^{-1}$)	0.67		0.19	−0.42	0.06
Females					
Weight (lb)	0.17				
T1 (min)	0.34		0.37		
HR 1-4 (bpm)	−0.14		0.01	−0.43	
$\dot{V}O_2$ ($l \cdot min^{-1}$)	−0.59		0.25	−0.48	0.05

$\dot{V}O_2$ = oxygen consumption.

TABLE 4. Regression equations for estimating $\dot{V}O_{2max}$.

	$\dot{V}O_2$ ($l \cdot min^{-1}$)			$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)		
Variable	Generalized	Male	Female	Generalized	Male	Female
Intercept	6.9652	9.0093	5.5597	132.853	154.899	116.579
Weight (lb)	0.0091	0.0106	0.0077	−0.0769	−0.0947	−0.0585
Age (yr)	−0.0257	−0.0277	−0.0236	−0.3877	−0.3709	−0.3885
Sex	0.5955	—	—	6.3150	—	—
T1	−0.224	−0.3115	−0.1713	−3.2649	−3.9744	−2.7961
HR 1-4	−0.0115	−0.0148	−0.0067	−0.1565	−0.1847	−0.1109
r	0.93	0.86	0.86	0.88	0.85	0.86
SEE	0.325	0.358	0.249	5.0	5.3	4.5

Sex: 0 = female, 1 = male; T1 = time for the first track walk expressed as minutes, hundredth of a minute; HR 1-4 = HR in bpm at the end of the last one-quarter mile for the first track walk.

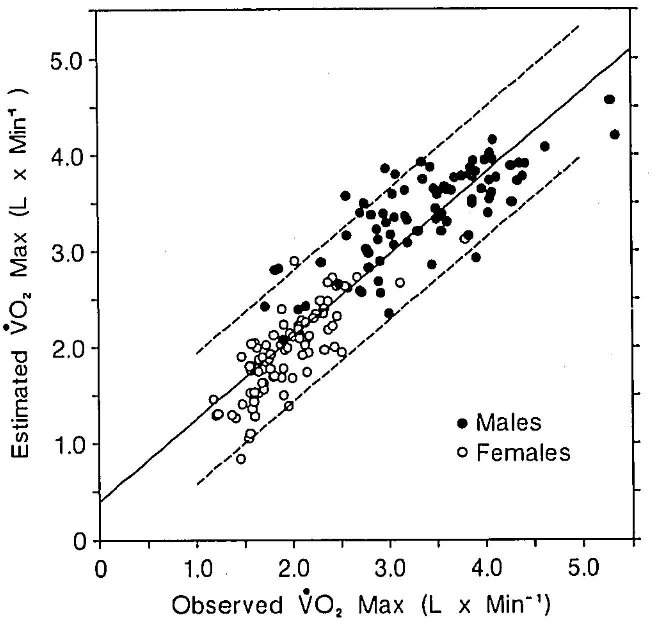

Figure 1—Observed vs estimated $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) for the CV group (N = 169). *Dashed line* represents the 95% confidence interval for the linear regression equation: Y = 6.9652 + (0.0091*WT) − (0.0257*AGE) + (0.5955*SEX) − (0.2240*T1) − (0.0115*HR1–4); r = 0.92, SEE = 0.335 $l \cdot min^{-1}$.

TABLE 5. Cross-validation of regression equations on cross-validation sample.

Cross-Validation Groups	$l \cdot min^{-1}$ Equation			$ml \cdot kg^{-1} \cdot min^{-1}$ Equation		
	Mean ± SD	r*	SEE	Mean ± SD	r	SEE
Generalized equation						
Total (N = 169)	2.67 ± 0.87	0.92	0.335	37.1 ± 9.1	0.88	4.4
30–39 yr (N = 48)	3.18 ± 0.75	0.93	0.278	44.5 ± 5.5	0.90	2.4
40–49 yr (N = 50)	2.81 ± 0.77	0.91	0.316	39.2 ± 6.7	0.85	3.6
50–59 yr (N = 35)	2.32 ± 0.80	0.90	0.354	32.9 ± 8.8	0.81	5.2
60–69 yr (N = 36)	2.11 ± 0.76	0.89	0.356	28.3 ± 6.2	0.74	4.2
Males (N = 83)	3.42 ± 0.47	0.81	0.277	41.1 ± 7.5	0.84	4.1
Females (N = 86)	1.94 ± 0.43	0.82	0.249	32.2 ± 7.8	0.86	4.0
Sex-specific equations						
Males (N = 83)	3.41 ± 0.56	0.82	0.324	42.1 ± 8.2	0.84	4.4
Females (N = 86)	1.94 ± 0.37	0.83	0.209	32.1 ± 7.1	0.86	3.6

* Zero-order correlation between laboratory determined $\dot{V}O_{2max}$ and $\dot{V}O_{2max}$ estimated from regression equations.

$kg^{-1} \cdot min^{-1}$ resulted in r = 0.88 and SEE = 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$. When this equation was cross-validated by decade, correlations ranged from r = 0.74 to r = 0.90, and SEEs varied from 2.4 to 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$. When this equation was cross-validated on the CV group males and females separately, the correlations were r = 0.84 and r = 0.86, and the SEEs were 4.1 and 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. The cross-validation results for the male and female equations were r = 0.84, SEE = 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$ and r = 0.86, SEE = 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively (Table 5). No significant differences were found between the observed and estimated $\dot{V}O_{2max}$ values for any of the cross-validation analyses.

DISCUSSION

Principles of cross-validation analysis have been presented by Lohman (20) with regard to the prediction of body density from skinfold measurements. These principles include: i) the preferred use of SEE over correlation coefficients when comparing equations which have been derived on different samples; ii) measured and predicted means and standard deviations of the validation sample should be similar; iii) large sample sizes are essential to develop and cross-validate regression equations; and iv) samples should closely reflect the population distribution. In contrast to many of the previous studies used to establish sub-maximal predictions of $\dot{V}O_{2max}$, the design of the present investigation met all of the criteria described by Lohman (20).

The generalized equations were developed on 174 subjects and cross-validated on 169 subjects with similar characteristics. These sample sizes are at least 2 to 3 times larger than most of the studies reviewed in Table 1. The validity coefficients (r = 0.92 and r = 0.88) for the $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ equations compare favorably with equations currently available. Figure 1 illustrates the individual data points for observed vs predicted $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) for the CV group. More importantly, the SEE in the validation group in the current study (0.325 $l \cdot min^{-1}$) is similar in magnitude to the range presented by numerous investigators (1, 2, 6, 8, 16, 28).

In addition, some of the test protocols involve strenuous work efforts and/or sophisticated laboratory equipment. The Fox test (9), for example, requires pedaling at a workload of 900 kpm for 5 min. For many individuals, this workload may be very difficult to maintain for that period of time and would, in effect, be a maximal effort. Ribisl and Kachadorian (26) present the lowest SEE (<2 $ml \cdot kg^{-1} \cdot min^{-1}$) for estimating $\dot{V}O_{2max}$ based on 100 yards, 400 yards, and 2-mile run times in 24 men (30 to 48 yr). This protocol may be inappropriate and potentially dangerous for sedentary and older populations, since vigorous efforts such as sprinting may result in cardiovascular complications or orthopedic injuries. Also, good estimation accuracy has been demonstrated by several investigations employing more elaborate testing procedures. Hermiston and Faulkner (12), using $FeCO_2$, tidal volume, RER, and fat-free weight, reported a correlation of r = 0.90; however, no SEE was presented. Metz and Alexander (25) and Mastrapaolo (22) found SEEs of 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$ and 0.17 $l \cdot min^{-1}$, respectively, using sub-maximal oxygen consumption, RER, diastolic blood pressure, and FeO_2. However, ease of test administration and need for sophisticated equipment limit these protocols to laboratory settings.

Although Cooper (4) and Doolittle and Bigbee (7) found high correlations between $\dot{V}O_{2max}$ and 12-min run/walk distance ($r = 0.90$) in adult males and ninth grade boys, respectively, other investigators have found lower correlations. Jackson and Coleman (14) reported validity coefficients of $r = 0.82$ in 22 boys (mean age = 11 yr) and $r = 0.71$ in 25 girls (mean age = 11 yr). Maksud and Coutts (21) reported correlations of $r = 0.65$ on boys 11 to 14 yr, and Katch et al. (19) noted a correlation of $r = 0.67$ in 36 college women.

In addition, McArdle et al. (24) pointed out that when the original data of Cooper (4) were restricted to college-aged men, the correlation was reduced from $r = 0.90$ to $r = 0.59$. When the generalized equation in the present study was restricted to more homogeneous age groupings (i.e., 30 to 39, 40 to 49, 50 to 59, 60 to 69 yr), the validation correlations ranged from $r = 0.89$ to $r = 0.93$, and the SEEs ranged from 0.278 to 0.354 $l \cdot min^{-1}$. There were no significant differences between observed and estimated $\dot{V}O_{2max}$ values (Table 5). In contrast to the results reported by McArdle et al. (24) on the Cooper data, the results from the present study indicate that our generalized equation maintains stable predictive accuracy even when used on smaller, more homogeneous age groups.

Cross-validation of the sex-specific equations in $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ resulted in smaller SEE for females (0.209 $l \cdot min^{-1}$ and 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to males (0.324 $l \cdot min^{-1}$ and 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$). This difference in SEE is due to the lower mean and smaller range of $\dot{V}O_{2max}$ values for the females (1.95 ± 0.43 $l \cdot min^{-1}$; and 32.2 ± 7.5 $ml \cdot kg^{-1} \cdot min^{-1}$) vs the values for males (3.40 ± 0.73 $l \cdot min^{-1}$ and 42.4 ± 10.5 $ml \cdot kg^{-1} \cdot min^{-1}$). These sex-specific SEEs are very similar in magnitude to those reported by Siconolfi et al. (28) (males = ±0.359, females = ±0.199 $l \cdot min^{-1}$). In that study (28), $\dot{V}O_{2max}$ prediction equations were developed on 35 males and 28 females (20 to 70 yr) using age and the predicted $\dot{V}O_{2max}$ from the Åstrand-Ryhming Nomogram as the predictor variables. The mean $\dot{V}O_{2max}$ values reported by Siconolfi et al. (28) for each sex were lower (males = 2.54, females = 1.48 $l \cdot min^{-1}$) compared to the $\dot{V}$ group in the present study (males = 3.31, females = 2.01 $l \cdot min^{-1}$). As a result, the SEEs expressed as a percent of the mean in the study by Siconolfi et al. (28) were 14 and 13% for males and females, respectively, compared to 10 to 11% for each sex in the present investigation.

When the generalized equation was used to estimate $\dot{V}O_{2max}$ for the male and female cross-validation groups separately, the SEEs were 0.277 and 0.249 $l \cdot min^{-1}$, respectively (Table 5). The sex-specific equation cross-validations resulted in SEEs of 0.324 and 0.209 $l \cdot min^{-1}$ for males and females, respectively. Although the female equation appears to yield a smaller SEE than the generalized equation, it should be pointed out that the female V group SEE was 0.249 $l \cdot min^{-1}$. Thus, sample differences could account for the discrepancy between the female V and CV groups. The slightly smaller SEE (0.209 $l \cdot min^{-1}$) of the CV group does not warrant the use of the sex-specific equations.

The methodology employed in the current study involved several track walks (2 to 5) per subject to account for any possible learning effect (e.g., improved walking mechanics) and to establish a stable walk time. In the original regression analysis, T1 and T2 refer to the two walk times within 30 s of one another. In 87% of subjects, this criterion was met in the first two walks, while the other 13% required additional walks. Since the performance of more than one walk may limit the practical utility of this test in field application, a cross-validation of the generalized equation was performed using HRs and time from the very first walk of each subject in the CV group. The estimated $\dot{V}O_{2max}$ based on the very first walk of 2.73 ± 0.97 $l \cdot min^{-1}$ (mean ± S.D.) compared favorably with the observed $\dot{V}O_{2max}$ (2.66 ± 0.94 $l \cdot min^{-1}$). The correlation ($r = 0.93$) and SEE (0.326 $l \cdot min^{-1}$) were virtually identical to those obtained using the more strict criteria. Thus for field use, data obtained from a single track walk appear sufficient to estimate $\dot{V}O_{2max}$ with the generalized equation. A probable explanation for this is that HR and walk time were inversely related. Any variation in walk time was accompanied by a concomitant inverse change in HR, thus preserving the accuracy of estimating $\dot{V}O_{2max}$ from the equation.

In summary, the present investigation generated six equations for estimating $\dot{V}O_{2max}$ in $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$ using age, gender, weight, and HR and time from a one-mile walk. The accuracy of all six equations, expressed as SEE, appears to be of similar magnitude. These equations are recommended for use in adults between 30 to 69 yr, based on the following:

1) The equations were developed and validated on relatively large samples.
2) The validation and cross-validation groups were homogeneous for all independent variables.
3) The generalized equation appears to be valid across a wide age range.
4) There were no differences between observed and estimated $\dot{V}O_{2max}$ or standard deviations in the cross-validation groups.
5) Accuracy of estimation represented by SEE was comparable to most of the other sub-maximal protocols reviewed.
6) As a field test, this protocol has the advantage of being simple, easy, and needing only a measured, flat one-mile surface, a stop watch, and the ability to measure pulse accurately.
7) The test requires only fast walking, which makes it useful in testing older or sedentary subjects.

Further validation will be useful in determining which equation(s) may be preferable in selected populations.

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