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Predicting Maximum Oxygen Uptake From a Modified 3-Minute Step Test

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Key words: bench height adjustment, exercise testing, fitness assessment, postexercise recovery heart rates

Maximum oxygen uptake (VO_2max) is considered the best indicator of aerobic fitness. However, because of the strenuous effort required by the participant, measuring VO_2max is often neither convenient nor safe for some individuals. Instrumentation, adequate facilities and qualified personnel also may limit the measurement of VO_2max. As a result, many investigators have attempted to predict VO_2max accurately from a variety of more convenient modalities, including step tests (Astrand & Rhyming, 1954; Fitchett, 1985; Francis & Brasher, 1992; Francis & Culpepper, 1989; Jette, 1977; Kasch, 1961; Kasch, Phillips, Ross, Carter, & Boyer, 1966; Kline et al., 1987; Siconolfi, Garber, Lasater, & Careleton, 1985; Thomas, Weller, & Cox, 1993; Wyndham, 1967).

Step tests vary in stepping frequency, bench height, test duration, the number of stages, and scoring method, but the main purpose of all step tests is to assess cardiorespiratory fitness. In 1961, Kasch validated a single-stage step test that used a 1-min postexercise recovery heart beat count (HBC) to assess cardiorespiratory fitness. The Kasch Step Test used a 12-inch bench, a stepping rate of 24 steps per minute, and duration of 3 min. Within 5 s after completing the step test, the participant sat on the bench and heartbeats were counted for 1 min. The total heartbeat count was referred to as the postexercise recovery heart rate and used to determine the individual's cardiorespiratory fitness category. In 1970, the National Young Men's Christian Association (YMCA) adopted the Kasch Step Test as a convenient, quick means of assessing cardiorespiratory fitness (Golding, 2000). Because of its wide use, the Kasch Step Test is often referred to as the YMCA 3-Minute Step Test and is used at hundreds of YMCAs as part of the National YMCA Physical Fitness Test Battery.

The HBC from the YMCA Step Test gives a quick categorization of cardio-respiratory fitness but does not provide an estimate of an individual's aerobic functional capacity or VO_2max. This limits the use of the YMCA Step Test in designing individualized training programs that are based on data rather than a fitness category. Metabolic Equivalent (MET; 1 MET = 3.5 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) values are often used in prescribing exercise to associate various activity intensities with individual functional capacity. Therefore, predicting VO_2max from the YMCA step test would be most beneficial to health professionals in designing exercise programs that give their clients safer exercise guidelines based on individual values.

Leg length may influence the results from step tests, thus, affecting the validity of the test results. Shahnawaz (1978) concluded that adjusting the bench height to the participant's leg length could enhance the validity of any type of step test. Adjusting the bench height to the participant's stature considers the biomechanical efficiency of stepping in participants with different leg lengths. Several authors have developed and validated a mathematical equation to compensate for the differences in standing height between individuals to more accurately assess cardiorespiratory fitness from McArdle's 3-Minute Step Test (Culpepper & Francis, 1987; Francis & Brasher, 1992; Francis & Culpepper, 1988, 1989; McArdle, Katch, Pechar, Jacobson, & Ruck, 1972). This model allowed the bench height to be adjusted so that all participants had a

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hip angle of approximately 73.3° when stepping up onto the bench. Culpepper and Francis (1987) reported that hip angles close to 73.3° resulted in the highest correlation between HBC from stepping and VO_2max. In women, the Culpepper and Francis model resulted in moderate *r* values of .8, .74, and .7 for stepping frequencies of 22, 26, and 30 steps/min, respectively between VO_2max and 15-s standing recovery HBCs (Francis & Culpepper, 1988, 1989). In men, Francis and Brasher (1992) also reported similar values of .77, .81, and .81 for stepping frequencies of 22, 26, and 30 step/min, respectively, between VO_2max and 15-s standing recovery HBCs. This suggests that the Culpepper and Francis model is valid for predicting VO_2max. The primary purpose of the present study was to determine whether adjusting bench height would result in a significant correlation between HBC from the YMCA 3-Minute Step Test and VO_2max.

Step tests can vary temporally with regard to measuring HBC and, thus, may affect the reliability of the step test. Watkins (1984) reported that the highest reliability in HBC from submaximal step tests occurs when the HBC is taken within the first 20 s of recovery. Therefore, the second purpose of this study was to determine if there was a better correlation between VO_2max and HBC with a shorter (15-s) HBC than the present 1-min HBC.

Method

Participants

Sixty healthy participants (27 women, 33 men) between the ages of 18 and 55 years voluntarily participated in this study with informed consent. Prior to any testing, participants were screened for cardiovascular and pulmonary disease and orthopedic problems through administration of the Physical Activity Readiness Questionnaire (PAR – Q) and a health history (Thomas, Reading, & Shepard, 1992). None of the participants were taking any medications, and none were cigarette smokers. Participants were instructed to refrain from exercise, consuming alcohol and caffeine 24 hr prior to the test and eating within 2 hr before the test. The Biomedical Sciences Committee of the Institutional Review Board at the University of Nevada–Las Vegas approved the study protocol.

The Modified YMCA 3-Minute Step Test

In the present study, the YMCA 3-Minute Step Test was modified by adjusting the bench height to the participant's stature. The equation used to determine the bench height was $H_f = (.189)(I_h)$ for women and $H_f = (.192)(I_h)$ for men, where, I_h represents the participant's height (in cm) and H_f represents the bench height (in cm) (Anderson, Green, & Messner, 1978; Culpepper & Francis, 1987). All other parameters used were the same as the original YMCA Step Test. For accuracy, a continuous electrocardiogram (EKG) was used to record the HBC.

Maximum Oxygen Uptake

VO_2max was measured by open circuit spirometry using the Vista System (VacuMed CO_2 and O_2 gas analyzers, model #'s 17520 and 17500; VacuMed, Ventura, CA) and a Quinton motor-driven treadmill (model # 24-72; Quinton, Bothell, WA). Before each test, the metabolic system was calibrated using 15.05% O_2 and 5.13% CO_2 gases. The protocol began with a 2-min warm-up during which participants walked comfortably (between 80.4 $m \cdot min^{-1}$ and 107.2 $m \cdot min^{-1}$, 0% grade) after which participants ran for 2 min at a self-selected speed at 0% grade (between 134.0 and 241.2 $m \cdot min^{-1}$). The workload was then increased by a grade of 2% every 2 min until participants reached volitional exhaustion. Oxygen uptake was considered maximal if any two of the following criteria were met: respiratory exchange ratio ≥ 1.1, a heart rate at or near age-predicted maximum (± 5 beats/min), and a $\leq$ 150 ml increase in VO_2 with an increase in workload. Of the original 60 participants, 44 (22 women, 22 men) met at least two of the above VO_2max criteria and were included in the statistical analyses. Their physical characteristics are shown in Table 1. During the test, heart rate was measured using a Polar Vantage XL (Polar Electro, Inc., Woodbury, NY) heart rate monitor. Heart rate, ratings of perceived exertion (original Borg scale), and respiratory measurements were taken every 30 s (Borg, 1998).

Experimental Protocol

All participants completed their testing in one session. Testing was performed between 9:30 a.m. and 7:30 p.m. in an air-conditioned environment. Participants wore appropriate apparel. Before any testing and after resting 5 min in a seated position, participants' heart rate was measured using a Polar Vantage XL heart rate monitor. Height (in cm) was taken with an anthropometer attached to the wall and weight (in kg) was measured using a digital Toledo load cell scale. Body mass index was calculated as kg/m^2. Percentage of body fat (see Table 1) was calculated according to the procedures described by Jackson and Pollock (1985).

The testing session began with the modified step test and was followed by the VO_2max test. Prior to the step test, the Polar Vantage XL heart rate monitor was removed, and the participant's skin was abraded in preparation for a standard (V5) EKG lead placement configuration. The step test procedures were explained and demonstrated. The EKG printout was used to determine the HBC at 15 s and 1 min from the step test. After completing the step test, the EKG leads were removed, and the Polar Vantage XL heart rate monitor was once again placed on the participant. The VO_2max test began after the participant's heart rate returned to resting levels (± 5 beats/min), which averaged about 15 min of rest between the tests.

Statistical Analyses

A Pearson product-moment correlation coefficient was calculated between measured VO_2max and both the 15-s and 1-min HBCs determined from the modified step test. Linear regression was used to develop prediction equations for VO_2max from the 15-s and 1-min HBCs. Fisher transformations were used to determine statistical significance between the 15-s and 1-min HBCs. An alpha level of .05 was selected.

Results

Tables 1 and 2 present a summary of the results. Figures 1 and 2 show the relationship between VO_2max and the 15-s and 1-min HBC for women and men. Regression

Table 1. Physical characteristics of participants and results from exercise protocols (*N* = 44)

	Age		Height (cm)		Weight (kg)		%Body fat		Step height (cm)		15-s HBC		1-min HBC		VO_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Women																
(*n* = 22)	22.8	4.8	165.4	5.0	63.4	9.7	29.0	5.9	31.4	1.0	31.9	7.4	107.0	26.7	42.6	9.1
Range	18–38		155–178		50–84		18–42		30–34		21–43		72–158		28–64	
Men																
(*n* = 22)	23.6	3.7	175.5	5.6	75.6	10.7	18.0	6.1	34.0	1.3	29.7	4.2	97.8	17.7	54.1	8.6
Range	18–31		165–186		55–105		10–32		32–36		22–40		71–144		40–70	

Note. HBC = postexercise recovery heart beat count; VO_2max = measured maximum oxygen uptake.

Table 2. Correlation and regression statistics between 15-s and 1-min HBCs and VO_2max

	15-s HBC	1-min HBC
All participants (*N* = 44)		
r value	-0.58	-0.61
Adjusted r^2	0.32	0.35
Standard error	8.76	8.53
Unexplained variability	0.48	0.45
Women (*n* =22)		
r value	-0.63	-0.60
Adjusted r^2	0.37	0.32
Standard error	7.20	7.50
Unexplained variability	0.63	0.68
Men (*n* =22)		
r value	-0.54	-0.64
Adjusted r^2	0.29	0.38
Standard error	7.60	6.90
Unexplained variability	0.71	0.62

Note. HBC = postexercise recovery heart beat count; VO_2max = measured maximum oxygen uptake.

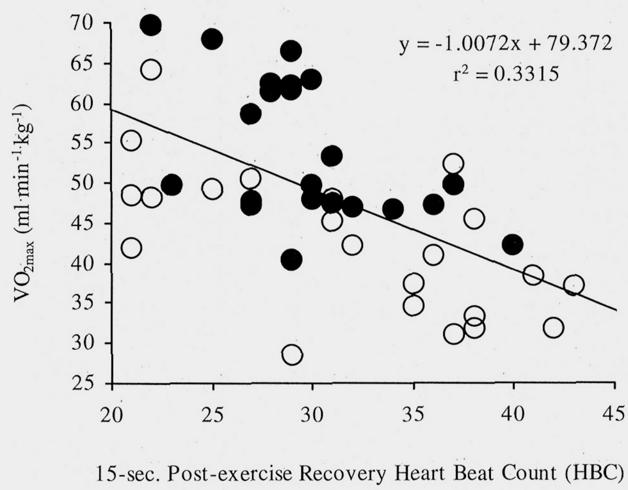

Figure 1. Regression line and equation between measured VO_2max and 15-s heart beat counts from the modified YMCA step test (o = women, • = men).

equations for women, men, and women and men combined are shown in Table 3. Correlation analyses between the 15-s and 1-min HBC and VO_2max resulted in significant ($p < .05$) r values ranging from -.54 to -.61. Regression statistics between the 15-s and 1-min HBC and VO_2max resulted in r^2 values of .33 and .37 for all participants, .40 and .36 for women, and .29 and .41 for men, respectively. The standard error of the estimate (*SEE*) for predicting VO_2max from the 15-s and 1-min HBC regression equations ranged from 6.9 to 8.76 $ml \cdot min^{-1} \cdot kg^{-1}$. Figures 3 and 4 show measured versus predicted VO_2max values from the 15-s and 1-min HBCs using the regression equations from Figures 1 and 2. Fisher transformations between the 15-s and 1-min HBCs resulted in nonstatistically significant Z values ($Z > 1.96$ = statistical significance) of .210, .149, and .475 for all participants, women, and men, respectively.

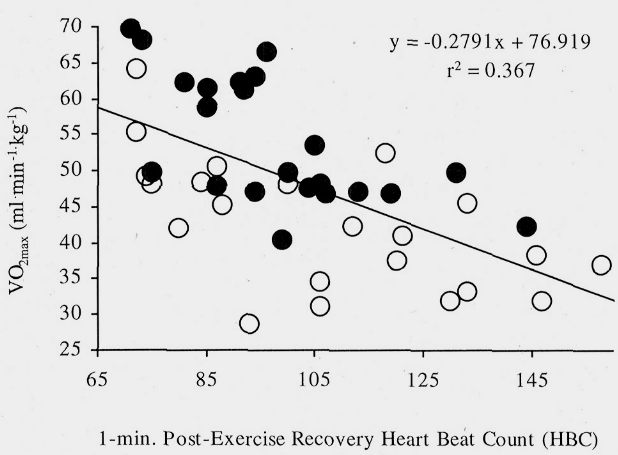

Figure 2. Regression line and equation between measured VO_2max and 1-min heart beat counts from the modified YMCA step test (o = women, • = men).

Table 3. Prediction equations for VO_2max from 15-s and 1-min HBCs

Group	15-s HBC	1-min HBC
All (N = 44)	y = -0.9675x + 77.643	y = -0.2805x + 76.710
Women (n =22)	y = -0.7764x + 67.344	y = -0.2021x + 64.209
Men (n =22)	y = -1.1114x + 87.130	y = -0.3143x + 84.841

Note. HBC = post exercise recovery heart beat counts; VO_2max = measured maximal oxygen consumption; All = females + males; x = HBC; y = predicted VO_2max.

Discussion

This study examined the relationship between measured VO_2max and HBCs obtained from the modified YMCA 3-Minute Step Test. HBCs at 15 s and 1 min were significant in predicting VO_2max and resulted in similar r and *SEE* values (see Table 2) to other studies (Culpepper & Francis, 1987; Francis & Brasher, 1992; Francis & Culpepper, 1988, 1989). This suggests that

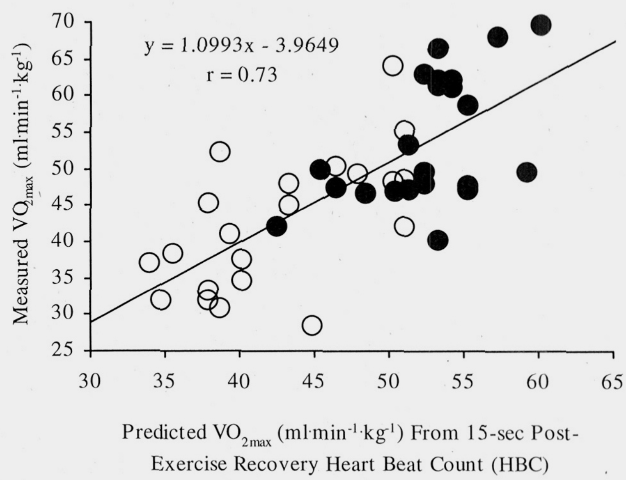

Figure 3. Measured versus predicted VO_2max from 15-s heart beat counts obtained from the modified YMCA step test (o = women, • = men). Points closer to the line of identity indicate good agreement between the predicted and measured VO_2max values.

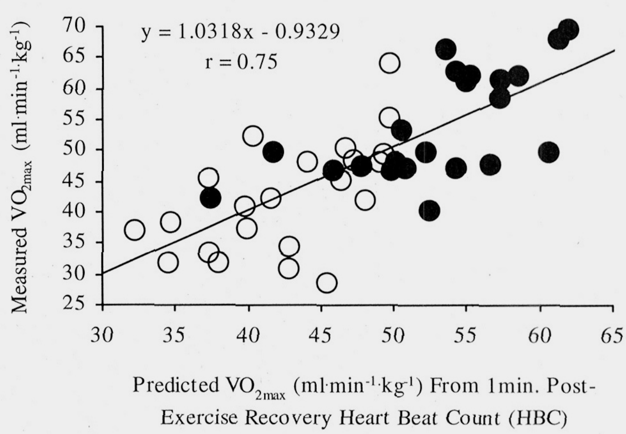

Figure 4. Measured versus predicted VO_2max from 1-min heart beat counts obtained from the modified YMCA step test (o = women, • = men). Points closer to the line of identity indicate good agreement between the predicted and measured VO_2max values.

the YMCA step test, when adjusted for leg length, may be a valid model for predicting VO_2max. However, a direct validation study is needed before these results can be used in the field.

Step tests can vary temporally with regard to measuring the HBC and, thus, may affect predicting VO_2max. Watkins (1984) reported that using a heart beat count within the first 20 s of recovery yielded the greatest reliability ($r = .94$) in scoring from a single-stage step test. McArdle et al. (1972) reported a reliability coefficient of .92 from a similar single-stage step test for a HBC also taken within the first 20 s of recovery. Our results conflict with these findings in that there was no significant difference between the 15-s and 1-min HBCs, suggesting that both time periods are equally valid. However, the modified YMCA step test used sitting HBCs in contrast to standing HBCs used in the previously described studies, which may account for the differences in our findings.

Individuals with different body composition may impact the results obtained during submaximal exercise testing and, thus, may limit the prediction of VO_2max. Cureton examined the effects of excess weight on aerobic capacity and distance running performance time in six recreational runners with above average VO_2max (as cited in Mariott & Gumstrup-Scott, 1992). Cureton reported that excess weight resulted in a significant increase in ventilation, VO_2 (l/min.), and heart rate, but it did not significantly affect VO_2max. Therefore, at any given submaximal workload, an individual will work at a higher percentage of their VO_2max with excess body weight. This suggests that if two individuals with the same VO_2max but different body composition (10% fat and 30% fat) performed the modified YMCA step test, the individual with 30% fat would have a higher exercising heart rate, which would be reflected in the HBC. The leaner individual would recover faster from the stepping exercise, because his or her heart rate was lower during the activity, thus giving a higher fitness rating. We speculate that differences in body composition may have contributed to some of the variability seen in our results and, thus, warrants further investigation.

Although our results show a significant correlation between VO_2max and 15-s and 1-min HBCs, there are several limitations to the present study. It assumes a discrepancy in HBC from the original YMCA step test among individuals with varying leg lengths. Because participants of this study did not perform the original YMCA 3-min step test, the validity of this assumption is uncertain. In addition, because predicting VO_2max from the original YMCA step test was not investigated, a comparison between the original test and the modified test could not be made. Last, validity and reliability of the modified YMCA step test could not be established due to a small participant pool and lack of a cross-validation group.

SEE values are typically used to determine the degree of error associated with prediction equations developed from regression statistics. In the present study, *SEE* values were higher than desirable (15–20% of the measured mean), possibly indicating a limitation to using HBCs to predict VO_2max. That is, HBCs may not be sufficiently sensitive to predict VO_2max accurately and precisely, compared to heart rates taken during an exercise test and may, therefore, be more useful as an overall characterization of VO_2max.

It can be concluded that there is a significant correlation between the HBCs obtained from the modified YMCA 3-Minute Step Test and VO_2max. In addition, there was no significant difference between using a 15-s and 1-min HBC. Further research is necessary to validate and determine the reliability of predicted VO_2max values from the modified YMCA 3-Minute Step Test.

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Authors' Notes

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