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Recumbent Stepper Submaximal Exercise Test to Predict Peak Oxygen Uptake

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Abstract

Purpose—The purpose of this study was to examine the ability of the YMCA submaximal exercise test protocol using a total body recumbent stepper (TBRS) to predict VO_2 peak.

Methods—Out of 112 individuals initially screened, one-hundred ten individuals with low to moderate cardiovascular disease risk met the inclusion criteria for participation in the study. The maximal exercise test used a motorized treadmill and the Bruce or modified Bruce protocol. Oxygen uptake was measured and analyzed through collection of expired gases using a metabolic measurement system. The submaximal exercise test was performed at least 24 hours later but no more than 5 days post maximal exercise testing. Participants were instructed to keep a pace of 100 steps per minute and the resistance increase every 3 minutes according to the protocol until fatigue, or 85% of HR max was achieved. A cross validation study was also performed to determine the accuracy of the prediction equation.

Results—Using a stepwise regression, we report that VO_2 peak can be predicted using a five element model including age, weight, sex, $watts_{\_endsubmax}$ and $HR_{\_endsubmax}$ ($F_{5,69} = 70.31$, $p < 0.001$). We report a strong correlation between the predicted VO_2 peak to the actual VO_2 peak.

Conclusion—These data suggest the YMCA submaximal exercise test can be used with the TBRS to predict VO_2 peak in healthy adults.

Keywords

aerobic fitness; rehabilitation; prediction model; exercise; cardiopulmonary; cross validation

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INTRODUCTION

Assessment of maximal oxygen uptake (VO_2 max) during an exercise test provides information related to overall health and is considered to be the "gold standard" for cardiorespiratory (aerobic) fitness (8, 9, 21). However, there are well-known limitations associated with maximal exercise testing such as expensive equipment and trained personnel, motivation of the participant to meet VO_2 max criterion, early onset of fatigue, physician availability for at-risk populations and exercise device (1, 6, 8–10, 13, 14, 21). Assessment of cardiorespiratory fitness and response to varying levels of exercise intensity is important and should be considered prior to the start of an exercise rehabilitation program. Submaximal exercise testing provides physical therapists, physicians, coaches, and health fitness professionals the opportunity to estimate VO_2 peak by determining the heart rate (HR) response to work rate (1, 21). VO_2 peak can be estimated by extrapolating HR response to a given workload (1, 17), or by using a prediction equation that could include variables such as HR, age or weight. (2)

Submaximal exercise tests have been developed for over ground walking, treadmill, cycle and recumbent ergometers. The submaximal test employed should be based on the needs of the participants and the functional, cardiorespiratory or metabolic limitations that may affect test performance (13, 19, 21, 22). As noted in a review article by Noonan and colleagues, "there is a need for standardized submaximal ergometer tests" for people with various physical impairments whether due to poor balance, obesity, musculoskeletal, or neuromuscular deficits (21). In recent reports, the total body recumbent steppers (TBRS) have been the exercise modality of choice for older adults (18) and are frequently used in exercise and rehabilitation settings due to accommodating a variety of physical impairments (10, 12, 20). The increasing interest in using a TBRS has prompted investigators to examine the reliability of the exercise device to produce accurate values for metabolic equivalents (METS) across various submaximal workloads (12, 20) when compared to those values generated by a portable metabolic unit (20).

However, there is still a need to use a standardized submaximal exercise test on the TBRS to inform healthcare professionals and clinical exercise physiologists about cardiorespiratory health. In addition, the submaximal exercise test may be used to test and measure the effectiveness of exercise programs for older adults and clinical populations. Therefore, the aim of the study was to develop a metabolic equation for estimating VO_2 peak from the Young Men's Christian Association (YMCA)(15) submaximal exercise test using the TBRS (Experiment 1). We hypothesized that a 5-element model calculated from the submaximal TBRS exercise test would predict (R^2 = 0.80) the measured VO_2 peak. A cross validation study with an independent sample was then conducted to determine the accuracy of the new prediction equation (Experiment 2).

METHODS

Participant

One-hundred twelve individuals were recruited from the community to participate in this study. During the screening process, only one individual did not meet the study criteria (high cardiac risk) and was not enrolled. One person signed the consent but then requested not to participate leaving 110 individuals with low to moderate cardiac risk (1) to participate in the study. Participant demographics are presented in Table 1. Inclusion criteria included: a) Men and women between 18–60 years of age; b) No physical limitations that would preclude them from participating in exercise testing; c) The ability to travel to 2 separate exercise testing sessions. Individuals were excluded if they presented with: a) High cardiac risk according to ACSM risk stratification categories;(1) b) Physical limitations on the treadmill or recumbent stepper; c) A diagnosis of cardiovascular or respiratory disease; and d) A bone or joint problem that may be aggravated by maximal exercise testing. The procedures used in this study were approved by the Institutional Review Board at Kansas University Medical Center. Written informed consent was obtained from all individuals prior to study participation.

Procedures

Each individual was screened for cardiovascular risk to determine eligibility into the study. Eligible participants were consented and then selected their physical activity level based on a non-exercise estimate of VO_2 peak (16). Participants were scheduled for both the maximal and submaximal exercise testing sessions. The maximal exercise test was scheduled initially, followed by the submaximal exercise test. The submaximal exercise test was scheduled between 24 hours and 5 days post-maximal testing. Individuals were scheduled for both tests at similar times of the day. Participants were informed not to consume food or drink (except water) within 2–3 hours of the exercise tests and avoid caffeinated products for 6 hours prior to the exercise test. Participants were asked to avoid vigorous physical activity for 24 hours prior to maximal testing. All participants were familiar with treadmill walking and running. However, not all participants were familiar with the TBRS and everyone had an opportunity to use the exercise device to practice the alternating, reciprocal movement pattern and step rate. This was performed prior to the submaximal exercise testing day.

Maximal Exercise Testing

The maximal exercise testing session was held at the University of Kansas Medical Center Research in Exercise and Cardiovascular Health (REACH) Laboratory. Height, weight, pre-exercise HR and blood pressure (BP) were obtained prior to exercise testing. A motorized treadmill was used for the maximal exercise test with a Bruce or modified Bruce protocol. Oxygen uptake was measured and analyzed through collection of expired gases using the ParvoMedics metabolic measurement system (Parvomedics Inc., Sandy, UT). Gas and flowmeter calibrations were performed on the metabolic cart according to the specifications of the manufacturer. The same individual (10 years of experience) performed calibration procedures for all exercise tests. The frequency of calibration was performed each morning and afternoon that testing was conducted. Room temperature and humidity were recorded for each test.

Each participant was familiarized with the exercise equipment, testing protocol and the Borg Rating of Perceived Exertion (RPE) Scale. A 12-lead ECG was used to monitor HR and rhythm continuously during the maximal exercise test. BP, HR, VO_2 and Borg's Rating of Perceived Exertion (RPE) were recorded during the last 30 seconds of each 3-minute stage. A 2-way, non-rebreathing valve, headgear, mouthpiece and nose clip were worn by the participants. Expired gases were collected continuously and oxygen uptake (VO_2) and carbon dioxide (VCO_2) production was averaged at 15-second intervals. American College of Sports Medicine guidelines (4) were used to determine test termination points. An Advanced Registered Nurse Practitioner was on call for all maximal exercise tests while the cardiology fellow was present for those individuals with moderate cardiovascular risk.

Submaximal Exercise Test

Participants were fitted with a Polar HR monitor for continuous use during the submaximal exercise test. Pre-exercise HR and BP were assessed prior to testing. Individuals were instructed to maintain a constant speed of 100 steps per minute (spm). The YMCA protocol (Table 2) was adapted for the TBRS (Nustep, Inc., Ann Arbor, MI). Participants started the test at 30 watts and resistance was increased every 3 minutes according to the protocol until volitional fatigue, (1) or 85% of age-predicted HR max was achieved. Participants were not given feedback regarding HR response in the first stage and "protocol track" in order to minimize anticipation of performance. Ten seconds prior to the end of the second and third minute of each stage, HR was recorded. If these two HR measures were within 5 bpm of each other, participants progressed to the next stage. (1) If the difference was greater than 5 bpm, an additional minute was performed to ensure a steady-state. Upon completion of the exercise test, the individual continued to step at a comfortable self-selected speed with resistance at 25 watts for 2 minutes or until HR returned to near baseline levels.

Sample Size Justification

Submaximal protocol development studies in adults have enrolled between 15–120 participants (7, 11, 12, 20, 23). Our initial intent was to enroll 50 participants as we proposed a 5-element model. After we reached the initial enrollment goals, we then targeted our enrollment to increase the number of older adults to expand the usefulness of a predictive model into a more clinically relevant age range.

Statistical Analysis

The arithmetic mean and standard deviation were used for descriptive statistics. Independent variables selected a priori for the regression were physical characteristics (body weight, sex and age) (1, 8) and outcomes from the submaximal exercise test (HR and work rate expressed in watts). Histograms for each variable were assessed for normal distributions and scatter plots were examined for outliers. A stepwise multiple regression model with the five variables was calculated for VO_2 peak. The validity of the model was assessed through analysis of colinearity statistics and Q-Q plots of unstandardized residuals. Paired t-tests were used to determine differences between testing environments. All analyses were conducted using SPSS statistical software (Version 17; SPSS, Inc, Chicago, IL) with the alpha level <0.05.

RESULTS

All data were normally distributed and no outliers were identified. No cardiac adverse event was reported during or after the graded exercise test. Participant effort was excellent with the mean respiratory exchange ratio (RER) value reported at **1.2** (5). Mean values for exercise testing variables are reported in Table 1. Since we performed the maximal and submaximal exercise tests in two different rooms, we recorded temperature and humidity. Although the temperature and humidity were controlled in each room, there were statistically significant differences The temperature of the exercise testing laboratory was 21.4 ± 2.3° C and the exercise room for submaximal testing was 21.9 ± 1.5° C, p = 0.002. Humidity in the exercise testing laboratory was 44.3 ± 7.5% whereas the exercise room was 42.0 ± 5.8%, p < 0.001.

The beginning stage of the YMCA protocol was modified to begin at 30 watts rather than the 25 watts because our pilot work (data not reported) indicated that the TBRS had difficulty keeping the 25-watt work rate constant at 100 spm. Rather than lower the step rate to 80 spm, the protocol was started at 30 watts.

There were no findings of multicollinearity with the variance inflation factor scores ranging from 1.1 to 2.8 suggesting the variance of the predictor variables were not redundant. Q-Q plot revealed that residual error was normally distributed. Using a stepwise regression, we found that VO_2 peak can be predicted using a five element model including age, weight, sex, $watts_{end\_submax}$ and HR_{end_submax} ($F_{5, 69}$= 70.31, p <0.001). This model resulted in an adjusted R^2 = 0.834, standard error of the estimate (SEE) = 4.09 ($ml*kg^{-1}*min^{-1}$), Table 3 and **total error = 4.11 ($ml*kg^{-1}*min^{-1}$)**. The contribution that each predictor variable made to predicting VO_2 peak is listed in Table 4. The predicted VO_2 peak values were strongly correlated to the actual values. (Figure 1)

Prediction Equation derived from the linear regression. VO_2 peak (ml*kg^{-1}*min^{-1}) = 125.707 + (−0.476)(age) + (7.686)(sex **[0= female; 1= male]**) + (−0.451)(weight) + (0.179)(Watt$_{send_submax}$) + (−0.415)(HR$_{end_submax}$)

Experiment 2 For the cross validation study, we determined that using a regression model with 5 predictors and a small value for shrinkage (0.075), an additional 40 participants would be needed. (3) Participant demographics and exercise testing results for Experiment 2 are listed in Table 5. Testing was conducted over a 4-week period after the initial prediction model was developed. Again, we monitored temperature and humidity in both testing rooms. The temperature of the exercise testing laboratory was 23.3 ± 0.7° C and the exercise room for submaximal testing was 22.9 ± 0.5° C, $p = 0.01$. Humidity in the exercise testing laboratory was 34.2 ± 1.8% whereas the exercise room was 37.4 ± 1.7%, $p < 0.001$. Values were entered into the VO_2 peak prediction model created in Experiment 1. The coefficient of determination between the predicted and actual VO_2 peak values in Experiment 2 was calculated. We then figured the amount of shrinkage (difference) between this coefficient of determination ($R^2 = 0.802$) and the value ($R^2 = 0.846$) from Experiment 1. The cross validation revealed shrinkage less than 0.075 confirming that the model was successful in predicting VO_2 peak in a new group of individuals.

DISCUSSION

This study sought to examine whether a metabolic equation for estimating VO_2 peak could be calculated from the YMCA submaximal exercise test using the TBRS. Our findings suggest that the YMCA submaximal exercise test using the TBRS can predict VO_2 peak in a group of heterogeneous individuals with low to moderate risk for cardiovascular disease.

Submaximal exercise testing can be used as a method for predicting peak exercise capacity and in the development of exercise prescription. Submaximal testing may be optimal in certain venues such as fitness centers, rehabilitation clinics, and assisted living facilities (20, 21)where maximal testing is not feasible. Previous reports have stated that the TBRS is commonly used by a wide variety of clinical populations (10, 20) in many different exercise/rehabilitation settings (12) because it can be used by a variety of clinical populations. Further, the TBRS was preferentially selected by older adults as the exercise modality for their exercise program (18). For these reasons, developing submaximal exercise tests employing the TBRS will provide information to healthcare and fitness professionals regarding baseline fitness and the effectiveness of the exercise intervention.

Mendelsohn and colleagues (20) used the YMCA submaximal exercise protocol with a group of older adults to evaluate whether or not the metabolic equivalents (METs) generated by the TBRS were similar to the data collected from a portable metabolic unit. Their findings demonstrated that data from the TBRS and metabolic unit were strongly correlated and not significantly different. The authors also examined reliability of the METS generated across workloads on different days with the same sample. The intraclass coefficient ranged between 0.87 and 0.91 for the test-retest reliability. Dalleck and colleagues (12) recently developed an equation to estimate steady-state oxygen uptake during submaximal exercise on the TBRS. The sample consisted of 20 men and 20 women ranging in age from 53–76 years of age. Their results demonstrated a standard error of the estimate and total error similar to that of other submaximal exercise tests. Further, in our previous work, we report that a maximal exercise testing protocol using the TBRS provided valid and reliable data in healthy adults (9). The results from the present study suggest the metabolic equation is valid for predicting VO2 peak and support the use of the TBRS for submaximal exercise testing using the YMCA protocol. Although data is limited, the TBRS as an exercise modality is consistent and reliable regarding the information generated.

To our knowledge, the current study is the first to employ the YMCA protocol to determine whether it is useful for prediction of VO_2 peak with the TBRS. We are also the first to study exercise testing using the NuStep T5xr. We chose to use this model for the submaximal exercise testing protocol for several reasons. First, this model has the availability of a menu option to display a constant power output. This is important during submaximal exercise testing because there is a linear relationship between work and HR. Maintaining constant power throughout the testing allowed the participants to reach a steady state HR(within 5bpm)(1) at the second and third minute of each stage of the YMCA protocol. We found that the previous model of the TBRS (TRS4000) is less likely to keep the workload constant if the step rate was not consistently maintained. If the step rate changed there was a concomitant change in the watts, which affects power output. With the T5xr in the constant power mode, we found that individuals at 100spm could vary approximately +/− 5spm and the constant power could be maintained. Second, this exercise modality is preferential for older adults (18) and can accommodate a variety of physical impairments and those deconditioned by chronic disease and disability (10, 12, 20). Using the submaximal exercise protocol and the TBRS would allow healthcare providers and clinical exercise specialists to assess cardiorespiratory fitness and prescribe exercise in individuals who would benefit most from physical activity.

Our current work is different from the few studies available using the TBRS in that we tested this submaximal exercise testing protocol in a range of ages (20 to 60 years) to predict VO_2 peak. These individuals were recruited from the community, University students, faculty and staff and local gyms. We had a select group of individuals from all ages interested in exercising to exhaustion and this may have biased our final prediction model. However, the metabolic equation derived from the regression final model is similar to those in the literature (1, 12) and has a low SEE (< 5 ml*kg^{-1}*min^{-1}). (2) We found that physical characteristics, weight and sex along with age and performance measures such as HR and work rate were important variables in predicting VO_2 peak. As demonstrated by the cross validation study, the final model retained accurate estimates of VO_2 peak. Statistically significant differences were found in temperature and humidity between the two testing rooms and may have influenced testing performance. However, we believe that these actual differences had minimal impact on performance.

In conclusion, these findings suggest that the YMCA submaximal exercise protocol can be successfully administered on the TBRS. The metabolic equation developed from this prediction model is useful in predicting VO_2 peak in individuals with low to moderate cardiovascular risk profiles according to ACSM standards. The YMCA submaximal protocol used in conjunction with the TBRS was easy to administer and did not require equipment other than the TBRS and HR monitor. Further studies are needed to determine whether this metabolic equation is appropriate to use in healthy adults over 60 years of age and clinical populations.

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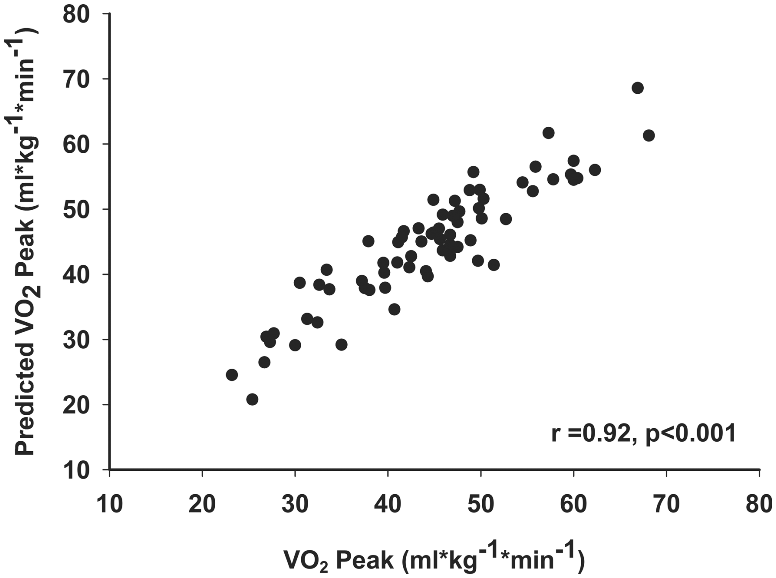

Figure 1.
Relationship between the predicted and actual VO_2 peak values (ml* kg^{-1}*min^{-1})

Table 1

Participant Demographics for Initial Study

Characteristics n = 70	Group Mean ± SD	
Sex: Male	36	
Age (years)	36.6 ± 11.2	
20–29		n = 28
30–39		n = 14
40–49		n = 15
50–60		n = 13
Height (m)	1.7 ± 0.09	
Weight (kg)	71.7 ± 13.1	
Body Mass Index (BMI)	23.8 ± 3.1	
Race		
African American	1	
Asian	7	
Caucasian	62	
Ethnicity		
Hispanic	1	
Non-Hispanic	67	
Not Specified	2	
Risk Stratification for Cardiovascular Disease Risk		
Low	66	
Moderate	4	
Resting HR (bpm)	62.0 ± 9.5	
Resting Systolic BP (mmHg)	126.4 ± 15.0	
Resting Diastolic BP (mmHg)	79.4 ± 8.0	
VO_2 peak ($ml*kg^{-1}*min^{-1}$)	44.5 ± 10.1	
RER (VCO_2/VO_2)	1.2 ± 0.08	
Peak HR (bpm)	177.5 ± 9.4	
RPE	18.7 ± 1.1	

Table 2

YMCA protocol adapted for the TBRS

	Stage 1 30 Watts			
	HR <80	**HR 80–89**	**HR 90–100**	**HR >100**
Stage 2	125 Watts	100 Watts	75 Watts	50 Watts
Stage 3	150 Watts	125 Watts	100 Watts	75 Watts
Stage 4	175 Watts	150 Watts	125 Watts	100 Watts

Table 3

Final regression model and sequence

Final Regression model for VO_2 peak ($ml*kg^{-1}*min^{-1}$)	
R	0.920
Adjusted R^2	0.834
p-value	<0.001

Outcome variable	Predictor variables	R	Adjusted R^2	R^2 Change	Std Error of the Estimate
VO_2peak	$Watts_{submax}$	0.627	0.384		7.89
	Age	0.795	0.621	0.237	6.19
	HR_{submax}	0.843	0.698	0.080	5.52
	Weight	0.878	0.756	0.048	4.97
	Sex	0.920	0.834	0.078	4.09

Table 4

Regression of VO_2peak ($ml*kg^{-1}*min^{-1}$) on predictor variables

Variable	Unstandardized Coefficients	Standard Error	Standardized Coefficients	p-value
Constant	125.707	11.975	-	<0.001
Age	−0.476	0.050	−0.533	<0.001
Sex (0= female, 1= male)	7.686	1.370	0.385	<0.001
Weight (kg)	−0.451	0.063	−0.586	<0.001
$Watts_{end\_submax}$	0.179	0.021	0.449	<0.001
$HR_{end\_ submax}$	−0.415	0.054	−0.549	<0.001

Table 5

Participant Demographics for Cross Validation Study

Characteristics n = 40	Group Mean ± SD	Range
Sex: Male	25	
Age (years)	38.2 ± 7.6	
20–29		n = 2
30–39		n = 26
40–49		n = 8
50–60		n = 4
Height (m)	1.7 ± 0.01	
Weight (kg)	78.1 ± 17.0	
Body Mass Index (BMI)	25.78 ± 5.7	
Race		
African American	1	
Asian	1	
Caucasian	37	
Native American	1	
Ethnicity		
Hispanic	1	
Non-Hispanic	39	
Risk Stratification for Cardiovascular Disease Risk		
Low	37	
Moderate	3	
Resting HR (bpm)	61.5 ± 8.3	
Resting Systolic BP (mmHg)	131.7 ± 12.0	
Resting Diastohc BP (mmHg)	76.4 ± 7.8	
VO_2 peak ($ml*kg^{-1}*min^{-1}$)	47.3 ± 9.3	
RER (VCO_2/VO_2)	1.2 ± 0.05	
Peak HR (bpm)	178.2 ± 9.9	
RPE	19.0 ± 0.86	