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Prediction of VO2 Peak Using a Sub-maximal Bench Step Test in Children

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ABSTRACT
The purpose of this study was to develop a valid prediction of maximal oxygen uptake from data collected during a submaximum bench stepping test among children ages 8-12 years. Twenty-seven active subjects (16 male and 11 female), weight 36.1 kg, height 144.4 cm and VO_2 47.4 ± 7.9 ml/kg/min participated. Subjects completed a maximal oxygen consumption test with analysis of expired air and a submaximal bench stepping test. A formula to predict VO_{2max} was developed from height, resting heart rate and heart rate response during the submaximum bench stepping test. This formula accounted for 71% of the variability in maximal oxygen consumption and is the first step in verifying the validity of the submaximum bench stepping test to predict VO_{2max}.

VO_2 max = -2.354 + (Height in cm * 0.065) + (Resting Heart Rate * 0.008) + (Step Test Average Heart Rate as a Percentage of Resting Heart Rate * -0.870)

Key words: VO_{2max} test, submaximal, children, bench stepping

INTRODUCTION

The measurement of maximal oxygen uptake (VO_{2max}) during a maximal exercise test continues to be the gold standard for determining cardiovascular fitness (17). However, there are a number of limitations to directly measuring $VO_{2max.}$ These limitations include logistical issues (e.g., cost, time, staffing), risk and discomfort to the participant of completing a maximum exercise test, and difficulty in motivating the participant to achieve maximal effort (12,17). These limitations are compounded when attempting to measure VO_{2max} in children (4). Sub-maximal exercise testing provides a feasible low cost alternative method of assessing cardiovascular fitness with minimal risk to the participant compared to maximal exercise testing (1). Furthermore, sub-maximal exercise testing can be conducted outside of the laboratory setting, which may be desirable for intervention studies (18), although some, like the 6-minute or one-mile walk require considerable space to administer. Many interventions conducted with children occur in community locations (16), where space and mobility concerns are especially pertinent. While sub-maximal exercise test are recognized as valid measurements among adult populations, a limited number of these types of tests have been validated in children (6,13). Shuttle runs have demonstrated to be a reliable and valid of predictor of VO_{2peak} children (9,14). Cycle ergometry physical work capacity tests at heart rates of 170 and 195 beats per minute have also demonstrated to be valid predictors of VO_{2peak} (3,10). Shuttle run and cycle ergometry testing require facilities to conduct testing and trained technicians to conduct the testing which are not always available in the field setting.

One type of sub-maximal exercise test that lacks many of the limitations noted above are bench stepping protocols (5).

Bench stepping protocols can be administered in a relatively small space in less than ten minutes, require a limited number of supplies, and have proven to be sensitive to changes in cardiovascular fitness in randomized clinical trials (15,19). Despite the ease of implementation and the widespread use of a variety of bench stepping protocols (e.g., Canadian Home Fitness Test, Harvard Step Test, YMCA Step Test), there currently exist no prediction equations with which to estimate maximal VO_{2max} from these bench stepping tests among children. Thus, the aim of this study was to determine if a valid prediction of VO_{2max} could be developed using a 3-minute bench stepping protocol among children 8-12 years old.

METHODS

A convenience sample of twenty-seven active subjects (16 male and 11 female) age 10.0 ± 1.2 years, weight 36.1 ± 6.0 kg, and height 144.4 ± 9.6 cm were recruited for participation in the study between November 2006 and December 2007. After obtaining approval from the institutional review board, informed assent and parental consent was obtained from the participants and their parent or guardian, respectively. Nineteen subjects took no medication on a regular basis, four were prescribed asthma medications, three antidepressants and one asthma and antidepressants. The sample reported being physically active, participating in an average of 416 minutes of physical activity per week or approximately one hour of physical activity per day by self-report. The subjects completed the 3-minute YMCA submaximum bench stepping protocol (5), waited 10 minutes and then completed the Bruce Treadmill Protocol to exhaustion (1). All subjects completed the data collection protocols in this same order. This submaximum bench stepping protocol required the subject to step up and down on a 12 inch bench at a rate of 24 rises per minute paced by metronome for 3 minutes. Subjects were provided with instruction and verbal encouragement to maintain the stepping pace throughout the test. A test was to be terminated if the participant's HR came within 10 bpm of their age predicted maximal heart rate (220 minus age) or if they were unable to maintain the prescribed stepping cadence for more than 10s. Heart rate was continually recorded at rest for 1 minute prior to beginning the submaximum bench stepping protocol via a Polar Heart Rate Monitor Model 610i. Heart rate was recorded immediately prior to engaging in the step protocol, following each minute of the submaximum bench stepping protocol immediately upon cessation of the protocol (t_0), at one (t_1), and two minutes (t_2) following cessation of the protocol. Mean heart rate was calculated from t_0, t_1, and t_2 heart rates. Subjects were provided a minimum 10-minute rest period after completion of the submaximum bench stepping protocol to allow their heart rate recovery to within 10 bpm of resting heart rate before initiating the Bruce Treadmill Protocol. Prior to the test, subjects were fitted with a pediatric head set and mouth piece. Expired gases were analyzed via Parvo Medics TrueOne 2400 (Sandy, UT) metabolic system and heart rate was recorded via a Polar Heart Rate Monitor Model 610i. Verbal encouragement was provided throughout the test. The test was terminated when the subject could no longer maintain the workload or a leveling off of oxygen consumption with increasing exercise intensity was identified.

Data analyses were performed in two steps using SPSS 16.0 statistical analysis package. The first step involved analysis to describe the sample. A correlation matrix was also constructed to determine which variables measured during the submaximum bench stepping protocol were significantly correlated with VO_{2max} determined from

Figure 1: Scattergram of $VO_2 \cdot L \cdot min$ measured during the GXT and $VO_2 \cdot L \cdot min$ estimated from three variables measured during the 3-minute step test.

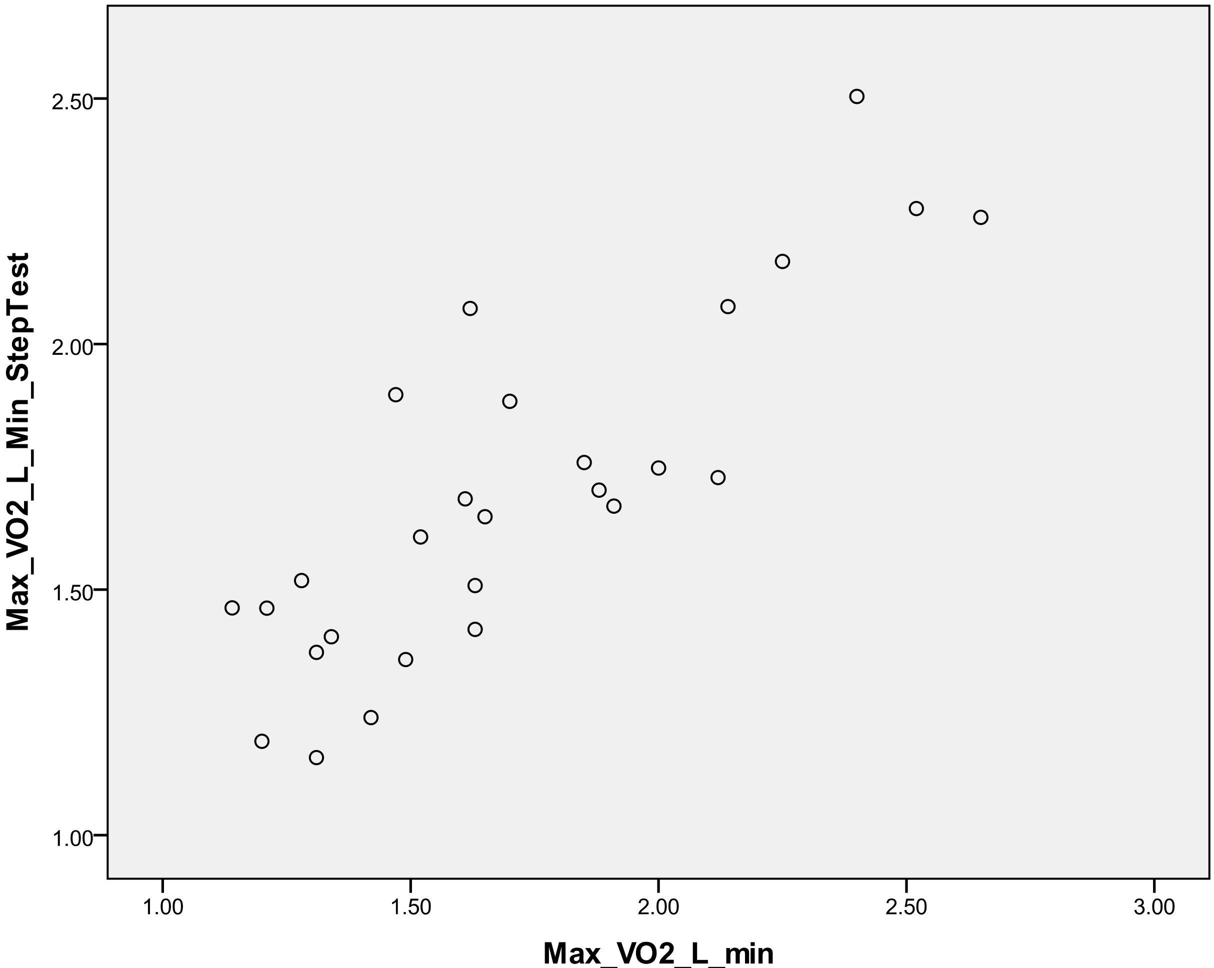

Table 1. Subject descriptors

	Minimum	Maximum	Mean	Std. Deviation
Age	8	12	10.0	1.2
Weight in Kg	26.1	48.0	36.1	6.0
Height in cm	130.8	163.8	144.4	9.6
BMI	14.2	20.0	17.4	1.7
Min of Activity per week	0	1680	417	393
Resting Heart Rate	60	120	85	15
VO2 Max (L/min)	1.14	2.65	1.71	0.42

completing the Bruce Treadmill Protocol. The second step involved constructing stepwise linear regression equations using measures that demonstrated a significant correlation with VO_{2max} determined from completing the Bruce Treadmill Protocol.

RESULTS

Table 1 indicates the sample mean age, average height, minutes of activity per week, resting heart rate, VO_{2max}, weight and BMI (2). A majority of the sample was male (59%). The sample's mean VO_{2max} determined from completing the Bruce Treadmill Protocol (1.7 ± 0.4 l/min) validated the sample's report of engaging in moderate amounts of physical activity on a weekly basis.

All subjects were able to complete the entire 3-minute step test. Pearson correlations were calculated in order to determine which variables measured during the submaximum bench stepping protocol were significantly correlated with VO_{2max} determined from completing the Bruce Treadmill Protocol (See Table 2). Table 2 indicates that maturation indicators, height, age and weight were all positively associated with VO_2 max. No measures of heart rate collected during the performance of the step test were correlated with VO_2 max.

Table 3 indicates the candidate variables identified in the correlations that significantly predicted VO_{2max}. All variables that demonstrated a significant correlation with VO_{2max} were initially entered into the stepwise regression. As Table 3 indicates, three variables collected during the submaximum bench stepping protocol were able to predict 71% of the variability in VO_2 max. The subject's height, resting heart rate and average heart rate during the 3-minute step test divided by resting heart rate significantly predicted VO_2 max and yielded the following prediction formula:

VO_{2max} = -2.354 + (Height in cm * 0.065) + (Resting Heart Rate * 0.008) + (Step Test Average Heart Rate as a Percentage of Resting Heart Rate * -.0870)

The ability of these three variables to predict VO_{2max} is supported further by Figure 1, which indicates a clear positive linear relationship between VO_{2max} measured during the Bruce Treadmill Protocol and VO_{2max} estimated from three variables measured during the submaximum bench stepping protocol.

DISCUSSION

The aim of the present investigation was to develop a valid prediction of VO_2 max from data collected through a submaximum bench stepping protocol among children. In light of the epidemic increase in childhood obesity in last decade (7,8,11) development of interventions are necessary to impact childhood obesity and outcome measures of cardiovascular fitness are required (6). In the field setting it is not feasible to conduct a Bruce Treadmill Protocol to determine VO_2 max. Furthermore, maximal testing increases the risk and limits the validity of the test in obese children due to local muscle fatigue. Sub-maximal bench stepping testing provides an effective low cost measurement of cardiovascular fitness with minimal risk to the subject (1). The submaximum bench stepping test can be conducted in 5' x 5' spaces (19). Hence, the test can be conducted in multiple locations with space limitations and commonly conducted in a climate-controlled environment.

The sample's resting heart rate indicated a wide range of values with higher values possibly attributable to anticipating the exercise assessments. Measures of heart rate prior to engaging in the exercise assessments were correlated with VO_{2max}. This finding may indicate that subjects with higher heart rates prior to engaging in the exercise test performed better on the assessment and this may further validate that these subjects were

Table 2. Correlations between VO_{2max} determined from completing the Bruce Treadmill Protocol and variables collected during the submaximum bench stepping protocol

		Maximum VO2 from Bruce Protocol
Height	Pearson Correlation	.750**
	Sig. (2-tailed)	.000
Age	Pearson Correlation	.702**
	Sig. (2-tailed)	.000
WtKg	Pearson Correlation	.704**
	Sig. (2-tailed)	.000
BMI	Pearson Correlation	.208
	Sig. (2-tailed)	.298
Resting _HR	Pearson Correlation	.545**
	Sig. (2-tailed)	.003
PreEX_HR	Pearson Correlation	.380
	Sig. (2-tailed)	.050
StepHR_1	Pearson Correlation	-.060
	Sig. (2-tailed)	.767
StepHR_2	Pearson Correlation	-.041
	Sig. (2-tailed)	.841
StepHR_3	Pearson Correlation	-.112
	Sig. (2-tailed)	.577
MaxHRstep	Pearson Correlation	-.138
	Sig. (2-tailed)	.494
StepPost1_HR	Pearson Correlation	.435*
	Sig. (2-tailed)	.024
StepPost2_HR	Pearson Correlation	.379
	Sig. (2-tailed)	.051
StepHRAVG1_3	Pearson Correlation	-.069
	Sig. (2-tailed)	.732
Step Test Average Heart Rate as a percentage of Pre Exercise Heart (PreHR-AveHR)/AvgHR	Pearson Correlation	-.466*
	Sig. (2-tailed)	.014
Max_VO2_L_Min_estimated from StepTest Protocol*	Pearson Correlation	.841**
	Sig. (2-tailed)	.000

*Correlation is significant at the .05 level (two tailed)
** Correlation is significant at the .01 level (two tailed)

Table 3. Stepwise linear regression predicting maximum VO2/L/min measured during the GXT

ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.	R Square
1	Regression	2.573	1	2.573	32.197	.000[a]	.46
	Residual	1.998	25	.080			
	Total	4.570	26				
2	Regression	2.975	2	1.488	22.386	.000[b]	.62
	Residual	1.595	24	.066			
	Total	4.570	26				
3	Regression	3.230	3	1.077	18.478	.000[c]	.71
	Residual	1.340	23	.058			
	Total	4.570	26				

a. Predictors: (Constant), Height

b. Predictors: (Constant), Height, Resting _HR

c. Predictors: (Constant), Height, Resting _HR, AVGHR1_3..PreHR1

d. Dependent Variable: Max_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.034	.838		-3.619	.001
	Height	.084	.015	.750	5.674	.000
2	(Constant)	-3.091	.765		-4.041	.000
	Height	.071	.014	.637	4.934	.000
	Base_HR	.009	.004	.318	2.462	.021
3	(Constant)	-2.354	.798		-2.948	.007
	Height	.065	.014	.588	4.774	.000
	Base_HR	.008	.004	.276	2.250	.034
	AVGHR1_3.percent.PreHR1	-.870	.416	-.248	-2.091	.048

a. Dependent Variable: Max_VO2_L_min

anticipating or motivated to perform well on the Bruce Treadmill Protocol. Average heart rate during the 3-minute step test divided by resting heat rate was significantly inversely correlated with VO_{2max} which further supports that subjects who were anticipating or motivated to engage in the Bruce Treadmill Protocol were also likely to perform well on this assessment.

Submaximal bench stepping testing provides increased control over the 6-minute walk test. Performance of the 6-minute walk test can be influenced by motivation, environmental conditions and competition among peers. The measurements of step testing are heart rate responses to a known workload set by a known step height and stepping rate controlled by metronome that involves more control of the participant's level of work.

Measurement of the physiological responses of children during exercise presents limitations. Diversity of the sample was limited by access to parents and children willing to participate in maximal exercise testing. Furthermore, institutional review board required exclusion criteria for orthopedic injuries, metabolic and cardiovascular disease limited the eligible subject pool to a convenience sample. The use of a fixed bench step height may create challenges for some small children. Recording measurements and calculating correction factors to compensate for inseam discrepancies would limit the ease of administering the test. Furthermore children gain mechanical advantage as they age, confounding longitudinal studies. These limitations can be argued for most fitness tests designed for children.

Step testing appears to be a simple to administer valid method to assess cardiovascular fitness and estimate VO_2 max. Existing sub-maximal testing protocols are based on correlations of data obtained from adult subjects that completed a maximal and sub-maximal exercise testing or require joint measurements to estimate mechanical advantage (4,6). The present study provides a formula to estimate cardiovascular fitness among children. Future studies including a test-retest are needed to determine the reliability of the YMCA 3-minute step test for children and the resulting estimate of VO_2 max in a larger, more diverse population.

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