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Development of an Exercise Test to Predict VO2max in Children and Adolescents

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DEVELOPMENT OF AN EXERCISE TEST TO PREDICT VO_2MAX IN CHILDREN AND ADOLESCENTS

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

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Master of Science

The purpose of this study was to evaluate the use of nonexercise (N-EX) data, specifically, the Perceived Functional Ability (PFA) and Physical Activity Rating (PA-R) questionnaires, with the treadmill walk-jog-run protocol to estimate VO_2max in 12 to 17 year old boys and girls. Ninety-one participants (49 males and 42 females) took part in this study. Data were collected via PFA and PA-R questionnaires, a walk-jog-run submaximal treadmill test, and a maximal graded exercise test (GXT). Data collected included gender, age, height, weight, PFA and PA-R scores, heart rate (HR), treadmill speed, maximal treadmill grade, respiratory exchange ratio (RER), rating of perceived exertion (RPE), and VO_2max.

Regression analysis resulted in the development of two valid and reliable models to predict VO_2max. Nonexercise and submaximal exercise test data were used to build the following model: VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$) = 11.201 + (6.877 x Gender; 0 = female; 1

= male) + (3.573 x treadmill speed; mph) – (0.174 x kg) + (0.405 x PFA score) + (0.653 x PA-R score) + (1.019 x age). The model resulted in an R^2 = 0.69 and a SEE = 5.16 $mL \cdot kg^{-1} \cdot min^{-1}$. Maximal exercise test data were used to build the following model: VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$) = -3.264 + (3.359 x Gender; 0 = female; 1 = male) – (0.082 x kg) + (7.351 x treadmill speed; mph) + (1.750 x maximal treadmill grade). The model resulted in an R^2 = 0.88 and a SEE = 3.16 $mL \cdot kg^{-1} \cdot min^{-1}$. The cross-validation PRESS statistics for both models demonstrated minimal shrinkage in the accuracy of the regression model.

The results of this study demonstrate, for the first time, that N-EX data can be used to accurately predict VO_2max in youth. The submaximal and maximal exercise tests validated in this study can be used to assess cardiorespiratory fitness of youth having a wide range on interests and fitness levels. In addition, the use of PFA and PA-R questionnaires enforces initiatives to increase physical activity among youth. Both exercise tests use a self-selected treadmill speed that elicits a steady-state HR of 70% of the participants age-predicted maximal HR. The use of a self-selected walking, jogging, or running speed accommodates youth with different levels of physical fitness, motivation, and interests. The exercise test protocol presented in this study is practical for use in schools, athletic facilities, and community fitness centers. The equipment required to administer the exercise test presented in this study is limited to a treadmill and a HR monitor. Together with the use of PFA and PA-R questionnaires, the submaximal and maximal exercise tests are efficacious to coaches, fitness professionals, and physical educators in a variety of settings.

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DEVELOPMENT OF AN EXERCISE TEST TO PREDICT VO_2MAX IN CHILDREN AND ADOLESCENTS

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Abstract

The purpose of this study was to evaluate the use of nonexercise (N-EX) data, specifically, the Perceived Functional Ability (PFA) and Physical Activity Rating (PA-R) questionnaires, with the treadmill walk-jog-run protocol to estimate VO_2max in 12 to 17 year old boys and girls. Ninety-one participants (49 males and 42 females) took part in this study. Data were collected via PFA and PA-R questionnaires, a walk-jog-run submaximal treadmill test, and a maximal graded exercise test (GXT). Data collected included gender, age, height, weight, PFA and PA-R scores, heart rate (HR), treadmill speed, maximal treadmill grade, respiratory exchange ratio (RER), rating of perceived exertion (RPE), and VO_2max.

Regression analysis resulted in the development of two valid and reliable models to predict VO_2max. Nonexercise and submaximal exercise test data were used to build the following model: VO_2max (mL·kg^{-1}·min^{-1}) = 11.201 + (6.877 x Gender; 0 = female; 1 = male) + (3.573 x treadmill speed; mph) – (0.174 x kg) + (0.405 x PFA score) + (0.653 x PA-R score) + (1.019 x age). The model resulted in an R^2 = 0.69 and a SEE = 5.16 mL·kg^{-1}·min^{-1}. Maximal exercise test data were used to build the following model: VO_2max (mL·kg^{-1}·min^{-1}) = -3.264 + (3.359 x Gender; 0 = female; 1 = male) – (0.082 x kg) + (7.351 x treadmill speed; mph) + (1.750 x maximal treadmill grade). The model resulted in an R^2 = 0.88 and a SEE = 3.16 mL· kg^{-1}·min^{-1}. The cross-validation PRESS statistics for both models demonstrated minimal shrinkage in the accuracy of the regression model.

The results of this study demonstrate, for the first time, that N-EX data can be used to accurately predict VO_2max in youth. The submaximal and maximal exercise tests validated in this study can be used to assess cardiorespiratory fitness of youth having a wide range on interests and fitness levels. In addition, the use of PFA and PA-R questionnaires enforces initiatives to increase physical activity among youth. Both exercise tests use a self-selected treadmill speed that elicits a steady-state HR of 70% of the participants age-predicted maximal HR. The use of a self-selected walking, jogging, or running speed accommodates youth with different levels of physical fitness, motivation, and interests. The exercise test protocol presented in this study is practical for use in schools, athletic facilities, and community fitness centers. The equipment required to administer the exercise test presented in this study is limited to a treadmill and a HR monitor. Together with the use of PFA and PA-R questionnaires, the submaximal and maximal exercise tests are efficacious to coaches, fitness professionals, and physical educators in a variety of settings.

Introduction

Cardiorespiratory fitness (CRF) is one of the five components of health-related physical fitness. The best measure of CRF is maximal (VO_2max) or peak (VO_2peak) oxygen consumption, which is the maximal or peak amount of oxygen that can be utilized during strenuous exercise. Assessments of CRF in the general population can be used to (a) educate participants about their current level of CRF relative to health-related norms and age- and gender-matched norms; (b) provide objective information useful in establishing reasonable goals to increase physical activity and improve CRF; and (c) provide information necessary to develop a safe, appropriate, and effective exercise program.

Due to the need for a costly metabolic cart and trained personnel, the direct measurement of VO_2max is generally reserved for laboratory settings. Maximal exercise testing of children requires additional knowledge of pediatric exercise physiology and exercise testing. Therefore, it is advantageous to have access to exercise tests that do not require the use of a metabolic cart and can be administered safely in nonlaboratory and nonclinical settings. Reasonable places to assess CRF of children are in a physical education class in the public schools or a community-based fitness program. With the advances in physical education, many schools now have treadmills in their physical education or athletic facilities. In addition, many community-based fitness facilities are open to children and adolescents. Due to public health initiatives to increase physical activity levels in children and adolescents, an exercise test should have educational value and be applicable to the development of a safe and effective exercise program designed to improve or maintain CRF. A treadmill-based exercise test would allow a physical educator, coach or trainer to administer a monitored and individualized exercise test. Many of the exercise tests that are currently available lack direct application to exercise programming (e.g., 20 meter shuttle run), require significant motivation for maximal performance (e.g., 1.5-mile run, 1-mile run/walk, 12-minute run), are performed in groups and lack needed individualized attention, or are weak predictors of CRF (Bonen, Heyward, Cureton, Boileau, & Massey, 1979; McMurray, Guion, Ainsworth, & Harrell, 1998; Metz & Alexander, 1971; Pitetti, Fernhall, & Figoni, 2002; Suminski, Ryan, Poston, & Jackson, 2004).

George (1996) reported the results of an exercise test that accurately predicted CRF in college-aged participants based on a self-selected jogging speed and the treadmill grade during the final stage of a maximal graded exercise test (GXT). Similar findings were reported in a sample of participants 18 – 65 years of age (George, Bradshaw, Hyde, LaMonte, Vehrs, Hager, and Yanowitz, 2007). In 1997, George, Stone, and Burkett demonstrated that accurate estimates of CRF could be made using a combination of demographic (e.g., age and gender), biometric (e.g., body weight, BMI) and nonexercise (N-EX) data. Nonexercise data included the summed responses from two perceived functional ability (PFA) questions and a modified physical activity rating (PA-R) question. Recently, George, Paul, Hyde, Bradshaw, Vehrs, Hager, et al. (2009) demonstrated that the estimation of CRF is improved when the prediction model includes both exercise (EX) and N-EX data. The EX data included the self-selected treadmill walking, jogging, or running speed that elicited a heart rate (HR) response greater than

70% of the participant's age-predicted maximal HR. The submaximal walk-jog-run protocol is advantageous because it easily accommodates participants of various fitness levels by using self-selected treadmill speeds and information gathered from N-EX questionnaires. The walk-jog-run exercise test is highly informative, educational, and applicable to the development of a personalized physical activity or exercise program. To the best of our knowledge, a protocol that allows the self-selection of walking, jogging or running speeds based on fitness level has not been developed for use in children and adolescents. Furthermore, the efficacy of N-EX data as predictors of CRF in children and adolescents has not been evaluated. Therefore, the purpose of this study was to evaluate the use of N-EX data, specifically, the PFA and PA-R questionnaires with the treadmill walk-jog-run protocol to estimate VO_2max in adolescents 12 to 17 years of age.

Methods

Participants

Ninety-one participants (49 males and 42 females) between 12-17 years of age were invited to participate in this study. Exclusion criteria included known conditions that may have reduced the participants' tolerance to exercise or increase the risk of untoward cardiovascular, pulmonary, or metabolic events during the maximal GXT. Females who were currently menstruating were scheduled to participate at a convenient date following their menstrual cycle.

Prior to the recruitment of participants and the collection of data, this study and its informed consent process was reviewed and approved by the Institutional Review Board (IRB) for the use of human subjects. Participants were recruited through flyers sent to faculty and staff, local youth groups, middle schools, high schools, and local recreational facilities.

Procedures

Participants were instructed to (a) wear comfortable shorts, shirt, and shoes appropriate for exercise; (b) drink plenty of fluids over the 24-hour period preceding the test to ensure normal hydration prior to testing; (c) refrain from eating food other than water, and from using substances such as tobacco, alcohol, and caffeine for at least three hours prior to their appointment; (d) avoid exercise or strenuous physical activity the day of the testing; and (e) get at least 6 to 8 hours of sleep the night before the appointment.

Pre-exercise Testing Procedures. Participants reported to the Exercise Physiology Lab where they completed an Assent Form and parents of participating children completed a Parents Permission Form prior to data collection to ensure informed consent. A preparticipation questionnaire was completed by a parent of each participant to screen for exclusion criteria. Each participant's height (cm) and weight (kg) was measured and recorded using a calibrated wall scale to the nearest one-half centimeter and a digital weight scale (Ohaus Model CD-33, Ohaus Corporation, Pine Brook NJ, USA) to the nearest one-tenth of a kilogram, respectively. Body mass index (BMI, kg/m^2) was calculated from measured height and weight values.

Each participant completed the PFA (George et al., 2009; George et al., 1997) and PA-R (Jackson, Blair, Mahar, Wier, Rossand, & Stuteville, 1990) questionnaires and then performed a submaximal walk-jog-run test and a maximal GXT on a treadmill. To determine the reliability of data, eleven of the participants repeated the submaximal walk-jog-run test and the maximal GXT on a second day. The responses to the two PFA questions were summed to give the PFA score. The single response to the PA-R question was recorded as the PA-R score. The PFA score and the PA-R score were used as independent variables in a prediction model to estimate VO_2max.

Exercise Testing. All exercise tests were performed on a motor-driven treadmill (Model TMX425C, Full Vision, Inc., Newton, KS). Metabolic and ventilatory responses to the maximal GXT were measured using a Truemax 2400 metabolic cart (Consentious Technologies, Sandy, UT). To facilitate the measurement of oxygen consumption throughout the GXT, participants were fitted with a mouthpiece and a nose clip to aid in measuring expired air. Heart rate was monitored using a radiotelemetry HR monitor (Polar Electro OY, Hong Kong) and rating of perceived exertion (RPE) was monitored using the Borg 15-point scale (Noble, Borg, & Jacobs, 1983). The calibration of the oxygen and carbon dioxide analyzers was checked using room air and a medical grade calibration gas of known concentrations. The metabolic cart was programmed to display and print metabolic and ventilatory data every 15 seconds.

Participants were given adequate time to become familiarized with walking and jogging on a treadmill. Each participant completed a submaximal treadmill test consisting of three stages corresponding to walking (3.0-4.0 mph), jogging (4.1-6.0 mph), and running speeds, (> 6.0 mph) (George et al., 2009). Each stage lasted 4 minutes and was conducted at a level grade. The participants progressed through the three stages until they reached a minimum of 70% of his or her age predicted maximum HR (220 – age), at which time, the submaximal treadmill test was terminated. After the submaximal treadmill test, the participants rested for at least 10 minutes before completing the maximal GXT. The self-selected treadmill speed which elicited a minimum of 70% of the age predicted maximum HR and the corresponding steady state HR were recorded and used as independent variables in a prediction model to estimate VO_2max.

Each participant completed a maximal GXT according to the protocol previously described (George, 1996; George et al., 2009). Participants walked for one minute at a slow pace; then walked, jogged, or ran for one minute at the self-selected treadmill speed that was previously determined to elicit a HR of at least 70% of the age-predicted maximal HR. The treadmill speed remained constant during the remaining stages of the exercise test as the grade was increased 1.5% each minute until the participant voluntarily terminated the test due to fatigue, despite verbal encouragement. Participants then performed an active walking cool down period at a self-selected speed at level grade. The highest treadmill grade that the participant was able to complete the entire minute stage was recorded and used as an independent variable in a prediction model to estimate VO_2max.

A maximal VO_2 value is sometimes characterized by a plateau in VO_2 despite further increases in work load. Some studies indicate that the VO_2 plateau-based criterion for VO_2max is unreliable for use with children (Armstrong, Balding, Gentle, Williams, & Kirby, 1990; Fredriksen, Ingjer, Nystad, & Thaulow, 1998; Paterson, Cunningham, & Donner, 1981; Rowland, 1996; Rowland & Cunningham, 1992). During a maximal GXT, children may reach maximal VO_2 values despite the lack of a plateau in VO_2 or the ability to meet other traditional criteria for a valid maximal exercise test (Brooks, Fahey,

& Baldwin, 2005; McMurray et al., 1998; Paterson, et al., 1981; Rowland & Cunningham, 1992; Sheehan, Rowland, & Burke, 1987). In this study, all exercise tests were terminated by exhaustion (i.e., when the participant was unwilling or unable to continue despite verbal encouragement). If any of the following additional criteria were met, we accepted the maximal VO_2 as VO_2max: (a) maximal RER > 1.0, (b) no further increase in HR despite an increase in workload, or (c) a maximal HR that was at least 85% of age-predicted maximal HR. VO_2max was defined as the highest 30-second average VO_2 value during the final minutes of the maximal GXT. Maximal HR was defined as the highest single HR value recorded during the maximal GXT.

Statistics

Statistical software (SAS 9.1, SAS Institute, Inc., Cary, NC) was used for all data analyses. An alpha level of $p < 0.05$ was maintained in all analyses. Multiple linear regression was used to generate a multivariate VO_2max regression equations using non-exercise, submaximal and maximal exercise data. To evaluate the strength of the independent variables that were used in the prediction model developed for adults (George et al., 2009), measured VO_2max was entered as the dependent variable and age, gender, body mass, PFA score, PA-R score and the self-selected treadmill walking/jogging/running speed were entered as independent variables in a regression analysis to predict VO_2max. To evaluate the contribution and significance of other independent variables, the measured VO_2max was again entered as the dependent variable and age, gender, body mass, BMI, PFA score, PA-R score, self-selected treadmill walking/jogging/running speed, steady state HR, maximal treadmill grade, and any reasonable two-way interactions were considered independent variables in a stepwise regression analysis to predict VO_2max. The relative accuracy of each VO_2max prediction model was evaluated using correlation coefficients, standard error of estimates (SEEs), and the percent SEE (SEE ÷ mean VO_2max). In addition, predicted residual sum of squares (PRESS) statistics (Holiday, Ballard, & McKeown, 1995) were calculated to estimate the degree of shrinkage one could expect when the prediction equation is used in a similar, but independent sample. The reliability of the measured and predicted VO_2max values of the eleven participants who completed the submaximal and maximal exercise testing on a second day was evaluated using a paired *t*-test and correlation coefficients.

Results

Descriptive statistics of the participants (N = 91), including demographic, biometric, EX, and N-EX data are presented in Tables 1–3. The N-EX data included PFA and PA-R scores. There was a general trend in both males and females that low PFA and PA-R scores were associated with higher BMI and lower VO_2max values. The EX data included the self-selected treadmill speed during the submaximal treadmill test, the corresponding steady state HR, and the maximal grade that the participant was able to complete one full minute of exercise during the maximal GXT. Only two participants reached at least 70% of age-predicted maximal HR during the walking stage (3.0–4.0 mph) of the submaximal exercise test. Eighty-one participants and the remaining eight participants reached at least 70% of their age-predicted maximal HR during the jogging (4.1-6 mph) and running (>6 mph) stages of the submaximal exercise test, respectively (Table 3).

During the maximal GXT, participants' maximal HR, RER, or RPE responses reflected a maximal level of exertion (Table 2). In addition to terminating the maximal GXT due to exhaustion, all of the participants reached at least 85% of the age-predicted maximal HR. All but eight participants reached an RER ratio of at least 1.0.

When evaluating the strength of the independent variables used in the previously published regression model to predict VO_2max in adults from age, gender, the self-selected walking-jogging-running treadmill speed, and N-EX data (George et al., 2009), the results were less favorable than previously reported in adults. Using the same independent variables to predict VO_2max of participants in this study resulted in the following model: VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$) = 11.201 + (6.877 x Gender; 0 = female; 1 = male) + (3.573 x treadmill speed; mph) – (0.174 x kg) + (0.405 x PFA score) + (0.653 x PA-R score) + (1.019 x age). The model explained 69% of the variance ($R^2 = 0.69$) and yielded an SEE of 5.16 $mL \cdot kg^{-1} \cdot min^{-1}$ (Table 4) and residuals ranging from -11.8 $mL \cdot kg^{-1} \cdot min^{-1}$ to 10.2 $mL \cdot kg^{-1} \cdot min^{-1}$. Figure 1 illustrates the predicted versus observed VO_2max values using the N-EX and submaximal exercise test data. The cross-validation PRESS statistics ($R_{PRESS} = 0.80$ and $SEE_{PRESS} = 5.37$ $mL \cdot kg^{-1} \cdot min^{-1}$), demonstrated acceptable shrinkage in the accuracy of the regression model (Table 4).

We also considered all other biometric, submaximal exercise, maximal exercise, and N-EX data from all participants (N=91) in building a model to estimate VO_2max. Of the nine possible predictor variables, the stepwise procedure dropped five from the model, including age, BMI, PFA score, PA-R score, and submaximal steady-state HR. The four remaining variables were used to derive the following model: VO_2max

($mL \cdot kg^{-1} \cdot min^{-1}$) = -3.264 + (3.359 x Gender; 0 = female; 1 = male) – (0.082 x kg) + (7.351 x treadmill speed; mph) + (1.750 x maximal treadmill grade). Figure 2 provides a scatter plot of predicted versus observed VO_{2max} values. The line of best fit through the data has a y-intercept not significant ($p > 0.05$) from zero and a slope not significant from one. The model explained 88% of the variance ($R^2 = 0.88$) and yielded an SEE of 3.16 $mL \cdot kg^{-1} \cdot min^{-1}$ (Table 5) and residuals ranging from -7.8 $mL \cdot kg^{-1} \cdot min^{-1}$ to 7.4 $mL \cdot kg^{-1} \cdot min^{-1}$. All four independent variables included in the model were highly significant. Based on standardized β-weights for the four independent variables included in the model, self-selected treadmill speed (0.541) and maximal treadmill grade (0.579) explained the largest amount of variance in VO_2max followed by gender (0.187) and body mass (-0.115). The cross-validation PRESS statistics ($R_{PRESS} = 0.93$ and SEE_{PRESS} = 3.25 $mL \cdot kg^{-1} \cdot min^{-1}$), demonstrated minimal shrinkage in the accuracy of the regression model (Table 5).

Eleven participants completed a maximal GXT on two separate days. The average difference (0.15 $mL \cdot kg^{-1} \cdot min^{-1}$) between the measured VO_2max values on the two days was not significant ($p = 0.87$). Likewise the average differences between the predicted VO_2max values calculated from the submaximal equation (1.95 $mL \cdot kg^{-1} \cdot min^{-1}$) and the maximal equation (1.90 $mL \cdot kg^{-1} \cdot min^{-1}$) on the two days were not significant ($p > 0.05$).

Discussion

The submaximal and maximal VO_2 regression equations developed in this study are noteworthy because they provide accurate and reliable estimates of CRF in children and adolescents 12 to 17 years of age.

Submaximal Exercise Test

The predictive accuracy of the submaximal regression model developed in this study is comparable to and more efficacious than other prediction models designed to predict CRF in youth. Our models are also applicable to males and females between 12−17 years of age. Metz and Alexander (1971) developed regression models (r = 0.355 −0.701; SEE 3.125−3.671 mL· kg^{-1}·min^{-1}) in a limited sample of 12−15-year-old males. Bonen et al. (1979) developed four regression models to predict VO_2max based on data collected from one hundred 6.7−14.8-year-old boys. The four regression models varied in predictive accuracy, with R values ranging from 0.52−0.95 and SEE values of 0.171 L·min^{-1} and 4.1−4.4 mL· kg^{-1}·min^{-1}. The regression equations developed by Metz and Alexander (1971) and Bonen et al. (1979) include VO_2 and/or VCO_2 as independent variables. It is unreasonable to expect nonclinical and nonresearch based facilities, such as public schools and community fitness centers, to have a metabolic cart and personnel who are trained in the use of such equipment, making such exercise testing protocols and regression equations not very efficacious.

To the best of our knowledge, this study is the first to evaluate the effectiveness of N-EX data in predicting CRF of youth. Our results demonstrate that in addition to submaximal exercise data, self-reported PFA and PA-R scores significantly contribute to the prediction of CRF in the 12 −17-year-old male and female participants in this study. George et al. (1997) reported that N-EX data, together with BMI and gender, can accurately predict VO_2max (R = 0.86, SEE = 3.34 mL· kg^{-1}·min^{-1}) in physically active college-age (18−29 years) men and women with comparable accuracy of regression models based on EX data. More recently, George et al. (2009) showed that N-EX data combined with EX data more accurately predicted VO_2max in adults 18-65 years of age than other published regression models. The beta weights of the PFA and PA-R scores in the regression equation developed in this study using submaximal EX data and N-EX data (Table 4) are comparable to the beta weight of the PFA and PA-R scores reported by George et. al. (2009).

We foresee that youth self-reports of physical activity may be problematic because, compared to adults, youth are less time conscious and sporadically engage in physical activity (Armstrong, et al., 1990). The efficacy of the PA-R and PFA questions necessitates familiarity with walking, jogging, and running; exercising continuously for extended periods of time or distances; comprehension of intensities of exercise that are "not too easy and not too hard"; and the ability to accurately gauge the time it takes to cover a given distance (George, 1997). Additionally, youth who are physically less active or dislike jogging or running may underestimate their PFA score due to their preference for walking as a mode of physical activity. Youth who engage primarily in unstructured play and physical activity may have difficulty in accurately reporting their PFA and PA-R scores.

Our submaximal exercise test has intrinsic educational value for children and adolescents. The current physical activity recommendation for children is to participate daily in 60 minutes or more of moderate- to vigorous-intensity physical activity (American College of Sports Medicine, 2006; Centers for Disease Control and

Prevention, 2009; Strong, Malina, Blimkie, Daniels, Dishman, Gutin, et. al., 2005). The submaximal exercise test protocol developed in this study includes a self-selected walking, jogging, or running treadmill speed that can be classified as moderate in intensity (i.e., eliciting at least 70% of the participants age-predicted maximal HR). This provides opportunities to teach youth about the selection of appropriate intensities of exercise that have health and fitness benefits. In conjunction with using the RPE scale, youth could learn to select appropriate walking, jogging, or running speeds that take into consideration personal interests and needs, motivation, and physical fitness. Once an individualized treadmill speed is determined, youth could walk, jog, or run outside at a similar pace. Teaching youth to exercise aerobically at a self-selected moderate-intensity enforces principles that promote lifetime physical activity. The use of the PFA and PA-R questionnaires provides teachers, trainers, physical educators, and coaches with opportunities to familiarize youth with submaximal and continuous forms of physical activity. The PFA and PA-R scores can also be used to track changes in an individual's physical or exercise program. Finally, youth with a low PA-R score can be encouraged to increase their daily and weekly physical activity and exercise.

Maximal Exercise Test

The regression equation developed from the maximal treadmill walk-jog-run test in this study is comparable in accuracy (R^2 = 0.88, SEE = 3.16 mL· kg^{-1}·min^{-1}, %SEE [%VO_2max] = 6.4) to the previously validated (George, 1996) exercise testing protocol in college-age adults (R^2 = 0.90, SEE = 2.13 mL· kg^{-1}·min^{-1}, %SEE [%VO_2max] = 4.8). In addition, the exercise test protocol and the subsequent estimation of VO_2max were highly reliable. After completing the submaximal exercise test to determine a walking, jogging, or running speed that elicited a HR response equivalent to at least 70% of age-predicted maximal HR, the maximal exercise test duration ranged from 3−12 minutes, depending on age and individual CRF level. This falls within the exercise test duration recommended by the American College of Sports Medicine (2006). In college adults, the maximal exercise test duration ranged from 4−8 minutes (George, 1996). The differences in test durations may be attributed to familiarity with treadmill exercise, ability to select an appropriate jogging speed, and differences in physiological responses (Plowman, 2001a, 2001b) between children and adults.

Our maximal exercise test is advantageous because it represents an individualized approach to exercise testing. The protocol allows participants to self-select a comfortable treadmill walking, jogging, or running speed that takes into consideration their personal levels of CRF. This is contrary to standardized exercise testing protocols that require participants, regardless of age and physical capacity, to exercise at pre-determined treadmill speeds and grades which also often represent large increments in oxygen cost between stages. The protocol presented in this study makes use of small increments in exercise intensity between stages. Based on the ACSM (2006) metabolic equations, the 1.5% increment in grade inherent in the exercise test developed in this study represents about a 2 $mL\cdot kg^{-1}\cdot min^{-1}$ increase in oxygen cost each stage (Spackman, George, Pennington, & Fellingham, 2001).

Even though the maximal exercise test developed in this study requires strenuous exercise, it can be used to assess CRF in youth with a wide range of CRF levels. The

CRF levels of the youth participating in this study ranged from 31−71 mL· kg^{-1}·min^{-1}. Based on the treadmill speed that elicited 70% of their age-predicted maximal HR during the submaximal exercise test, 81 of participants in this study jogged (4.1-6.0 mph) during the maximal exercise test, whereas two of the participants walked (3.0-4.0 mph) and eight participants ran (> 6.0 mph). As expected, those who walked during the exercise test were heavier, had higher BMI and percent body fat values, lower self-reported PFA and PA-R scores and had lower fitness levels (VO_2max < 37 mL· kg^{-1}·min^{-1}) than those who jogged or ran. Participants who jogged during the exercise test had body weights, BMI and percent body fat values, PFA and PA-R scores, and VO_2max values between those who walked and those who ran during the exercise test. VO_2max values of those who jogged during the exercise test ranged from the lowest (31 mL· kg^{-1}·min^{-1}) to the highest (70 mL· kg^{-1}·min^{-1}) values. Those who ran during the exercise test had CRF levels ranging from 50−71 mL· kg^{-1}·min^{-1} and were thus not limited to only the upper levels of CRF. Although those youth who are physically fit may be more inclined to select an exercise test such as the maximal exercise test developed in this study, all youth, regardless of their fitness level, could perform the maximal exercise test at a self-selected speed that was based on their personal HR response. Compared to performance-based alternatives, such as the 1-mile run, 12-minute run and 1.5-mile run, relatively little time is spent in strenuous exercise in the maximal exercise test validated in this study. The maximal treadmill protocol developed in this study is also advantageous for all youth, including those who are less fit, because it can be easily administered and supervised by a physical educator, coach, or trainer. Because the maximal exercise test is performed using a walking, jogging or running speed that is individualized, it provides opportunities to teach youth about appropriate intensities of exercise that are useful in developing or maintaining CRF.

The regression equation for the maximal exercise test will only provide accurate results when participants exert maximal efforts. In a laboratory setting, maximal exertion is confirmed using metabolic data such as VO_2 and RER values. The advantage of the maximal exercise test developed in this study is that it can produce accurate predictions of VO_2max without the use of equipment that is not typically available to facilities that involve youth participants. In such settings, maximal exertion during the exercise test can be confirmed by (a) volitional termination of the exercise test despite verbal encouragement, (b) physical signs of fatigue, (c) a maximal HR within 15 beats of their age-predicted maximal HR, and (d) a self-reported maximal RPE value of at least 18 using the (15-point scale).

The ACSM (2006, p 123) includes an RPE > 17 as one of the subjective indicators of maximal effort. We recommend that physical educators, coaches, trainers, and others who work with youth, help youth become familiar with the RPE scale. An example of how this could be done is to fit the participant with a HR monitor and have him/her walk on the treadmill at a slow speed. After a few minutes have the participant select a value on the RPE scale—and its corresponding description of the intensity of exercise—that best describes his/her perception of the overall difficulty of the exercise. Increase the speed of the treadmill to a brisk walk and repeat the selection of a RPE value. Continue to do this through five to six walking, jogging, and running speeds. As the participant progresses through a range of exercise intensities, note the exercise HR and signs of exertion (e.g., sweating). Educating youth about the RPE scale may result in a more accurate perception of exercise intensity during the maximal exercise test and a greater confidence in selecting a personalized and appropriate intensity of aerobic exercise when training to improve or maintain CRF.

The exercise test protocols presented in this study are practical for use in schools, athletic facilities, and community fitness centers. The two regression models presented in this study are applicable to males and females between the ages of 12−17 years of age. The model that includes submaximal EX data and N-EX data predicts CRF with reasonable accuracy. The PFA and PA-R questionnaires can be easily administered and the submaximal exercise test is safe and offers educational value. The regression model that includes maximal exercise data has at least comparable, if not stronger predictive accuracy than other prediction models designed to predict CRF in youth. Both regression models should prove useful to coaches, fitness professionals, and physical educators by allowing them to administer to adolescents a monitored exercise test which accurately predicts VO_2max.

References

American College of Sports Medicine. (2006). *ACSM's Guidelines for Exercise Testing and Prescription.* (7th ed.). Baltimore, Lippincott Williams & Wilkins.

Armstrong, N., Balding, J., Gentle, P., Williams, J., & Kirby, B. (1990). Peak oxygen uptake and physical activity in 11- to 16-year olds. *Pediatric Exercise Science*, 2, 349-358.

Bonen, A., Heyward, V. H., Cureton, K. J., Boileau, R. A., & Massey, B. H. (1979). Prediction of maximal oxygen uptake in boys, ages 7-15 years. *Medicine and Science in Sports, 11*(1), 24-29.

Brooks, G. A., Fahey, T. D., & Baldwin, K. M. (2005). *Exercise physiology: Human bioenergetics and its applications* (4th ed.). New York: McGraw-Hill.

Centers for Disease Control and Prevention. (2009). How much physical activity do adults need? Retrieved April 14, 2009, from http://www.cdc.gov/physicalactivity/everyone/guidelines/children.html

Fredriksen, P. M., Ingjer, F., Nystad, W., & Thaulow, E. (1998). Aerobic endurance testing of children and adolescents – A comparison of two treadmill-protocols. *Scandanavian Journal of Medicine and Science in Sports, 8*, 203-207.

George, J. D. (1996). Alternative approach to maximal exercise testing and VO_2max prediction in college students. *Research Quarterly for Exercise and Sport, 67*(4), 452-457.

George, J. D., Bradshaw, D., Hyde, A., LaMonte, M. J., Vehrs, P. R., Hager, R. L., & Yanowitz, F. G. (2007). A maximal graded exercise test to accurately predict VO_2max in 18-65-year-old adults. *Measurement in Physical Education and Exercise Science,* 11(3), 149-160.

George, J. D., Paul, S. L., Hyde, A., Bradshaw, D. I., Vehrs, P. R., Hager, R. L., et al. (2009). Prediction of maximum oxygen uptake using both exercise and non-exercise data. *Measurement in Physical Education and Exercise Science, 13*(1), 1-12.

George, J. D., Stone, W. J., & Burkett, L. N. (1997). Non-exercise VO_2max estimation for physically active college students. *Medicine and Science in Sports and Exercise, 29*(3), 415-423.

Holiday, D. B., Ballard, J. E., & McKeown, B. C. (1995). PRESS-related statistics: Regression tools for cross-validation and case diagnostics. *Medicine and Science in Sports and Exercise, 27*, 612–620.

Jackson, A. S., Blair, S. N., Mahar, M. T., Wier, L. T., Rossand, R. M., & Stuteville, J. E. (1990). Prediction of functional aerobic capacity without exercise testing. *Medicine and Science in Sports and Exercise, 22*(6), 863-870.

McMurray, R. G., Guion, W. K., Ainsworth, B. E., & Harrell, J. S. (1998). Predicting aerobic power in children. *Journal of Sports Medicine and Physical Fitness, 38*, 227-233.

Metz, K. F., & Alexander, J. F. (1971). Estimation of maximal oxygen uptake from submaximal work parameters. *Research Quarterly, 42*(2), 187-193.

Morrow, J. R., & Freedson, P. S. (1994). Relationship between habitual physical activity and aerobic fitness in adolescents. *Pediatric Exercise Science, 6*(4), 315-329.

Noble, B. J., Borg, G. A. V., & Jacobs, I. (1983). A category-ratio perceived exertion scale: Relationship to blood and muscle lactates and heart rate. *Medicine and Science in Sports and Exercise, 15,* 523-528.

Paterson, D. H., Cunningham, D. A., & Donner, A. (1981). The effect of different treadmill speeds on the variability of VO_2 max in children. *European Journal of Applied Physiology and Occupational Physiology, 47*, 113-122.

Pitetti, K. H., Fernhall, B., & Figoni, S. (2002). Comparing two regression formulas that predict VO_2peak using the 20-m shuttle run for children and adolescents. *Pediatric Exercise Science, 14*, 125-134.

Plowman, S. A. (2001a). Children aren't miniature adults: Similarities and differences in physiological responses to exercise part 1. *ACSM's Health & Fitness Journal, 5*(5), 11-17.

Plowman, S. A. (2001b). Children aren't miniature adults: Similarities and differences in physiological responses to exercise part 2. *ACSM's Health & Fitness Journal, 5*(6), 13-18.

Rowland, T. W. (1996). *Developmental exercise physiology*. Champaign: Human Kinetics.

Rowland, T. W., & Cunningham, L. N. (1992). Oxygen uptake plateau during maximal treadmill exercise in children. *Chest, 101*, 485-489.

Sheehan, J. M., Rowland, T. W., & Burke, E. J. (1987). A comparison of four treadmill protocols for determination of maximum oxygen uptake in 10- to 12-year-old boys. *International Journal of Sports Medicine, 8*, 31-34.

Spackman, M. B., George, J. D. Pennington, T. R., & Fellingham, G. W., (2001). Maximal GXT protocol preferences in relatively fit college students. *Measurement in Physical Education and Exercise Science*, 5(1), 1-12.

Strong, W. B., Malina, R. M., Blimkie, C. J. R., Daniels, S. R., Dishman, R. K., Gutin, B., Hergenroeder, A. C., Must, A., Nixon, P. A., Pivarnik, J. M., Rowland, T., Trost, S., and Trudeau, F. (2005). Evidence based physical activity for school-age youth. *Journal of Pediatrics*, 146, 732-737.

Suminski, R. R., Ryan, N. D., Poston, C. S., & Jackson, A. S. (2004). Measuring aerobic fitness of Hispanic youth 10 to 12 years of age. *International Journal of Sports Medicine, 25*, 61-67.

Table 1

Participant Descriptive Characteristics

Age and Gender	Height (m)	Body Mass (kg)	BMI ($kg \cdot m^{-2}$)	Body Fat (%)	PFA	PA-R	VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)
MALES							
12 (n = 12)	1.52 ± 0.58	45.2 ± 6.1	19.5 ± 2.6	19.5 ± 7.6	17.6 ± 4.4	5.8 ± 1.9	52.3 ± 9.6
13 (n = 13)	1.63 ± 0.12	49.2 ±10.6	18.3 ± 2.7	15.4 ± 5.8	19.2 ± 4.5	8.2 ± 2.2	52.4 ± 8.4
14 (n = 8)	1.67 ± 0.07	58.7 ± 9.2	21.0 ± 2.8	14.5 ± 5.0	18.4 ± 2.1	7.4 ± 2.4	54.6 ± 3.2
15 (n = 8)	1.74 ± 0.06	69.6 ±14.4	22.8 ± 4.2	14.0 ± 2.9	17.2 ± 5.7	6.5 ± 2.6	49.5 ± 9.1
16 (n = 5)	1.78 ± 0.12	60.8 ± 9.9	19.0 ± 1.4	10.6 ± 4.1	16.8 ± 7.8	9.0 ± 1.2	60.2 ± 6.3
17 (n = 6)	1.80 ± 0.03	70.6 ± 4.1	21.8 ± 1.7	10.8 ± 1.3	20.5 ± 4.7	7.0 ± 3.3	58.7 ± 6.3
FEMALES							
12 (n = 1)	1.36 ± 0.0	30.9 ± 0.0	16.5 ± 0.0	24.9 ± 0.0	8.0 ± 0.0	2.0 ± 0.0	43.7 ± 0.0
13 (n = 9)	1.58 ± 0.07	55.5 ±12.9	21.9 ± 4.5	28.7 ± 7.5	13.1 ± 4.3	5.1 ± 3.1	41.0 ± 6.3
14 (n = 4)	1.62 ± 0.10	68.3 ±15.9	26.2 ± 6.1	37.8 ± 5.8	12.5 ± 4.1	3.7 ± 3.6	36.9 ± 6.8
15 (n = 10)	1.62 ± 0.05	57.3 ± 6.4	21.6 ± 2.2	25.7 ± 4.1	15.0 ± 4.8	5.7 ± 2.4	43.3 ± 3.7
16 (n = 12)	1.64 ± 0.48	58.3 ±12.7	21.4 ± 4.1	25.3 ± 5.7	16.1 ± 3.7	6.1 ± 2.7	46.0 ± 6.6
17 (n = 6)	1.61 ± 0.04	60.3 ± 6.7	23.0 ± 1.6	26.1 ± 2.8	14.5 ± 6.3	7.2 ± 1.7	46.2 ± 6.0

Note. BMI = body mass index. PFA = perceived functional ability score. PA-R = physical activity rating.

Table 2

Participant Descriptive Statistics

	Male (n = 49)	Female (n = 42)	Total (N = 91)
Age (years)	14.0 ± 1.7	14.9 ± 1.4	14.5 ± 1.6
Height (m)	1.66 ± 0.12	1.61 ± 0.07	1.64 ± 0.1
Body mass (kg)	56.9 ± 13.5	58.1 ± 11.8	57.5 ± 12.7
BMI ($kg \cdot m^{-2}$)	20.3 ± 3.1	22.2 ± 3.9	21.1 ± 3.6
Body Fat (%)	15.0 ± 6.0	27.2 ± 6.2	20.6 ± 8.6
PFA score	18.3 ± 4.7	14.4 ± 4.6	16.5 ± 5.3
PA-R score	7.1 ± 2.5	5.6 ± 2.7	6.4 ± 2.7
Submaximal Exercise Test			
Treadmill speed (mph)	5.4 ± 0.7	4.9 ± 0.5	5.2 ± 0.6
Steady-state HR	162.0 ± 10.3	168.0 ± 13.2	164.8 ± 12.0
% age-predicted maximal HR	78.5 ± 5.1	81.7 ± 6.4	79.9 ± 5.9
RPE	12.3 ± 1.9	12.7 ± 1.6	12.5 ± 1.8
Maximal Exercise Test			
Maximal grade	10.6 ± 3.0	8.7 ± 2.6	9.8 ± 2.9
Maximal HR	198.8 ± 6.5	199.7 ± 7.1	199.2 ± 6.8
% age-predicted maximal HR	95.6 ± 3.3	97.4 ± 3.4	96.9 ± 3.4
Maximal RER	1.07 ± 0.06	1.06 ± 0.06	1.07 ± 0.06
Maximal RPE	18.4 ± 1.4	18.6 ± 1.3	18.5 ± 1.4
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	53.9 ± 8.2	43.4 ± 6.2	49.1 ± 9.0

Note. All values are mean ± SD. BMI = body mass index. PFA score = sum of responses to both perceived functional ability questions. PA-R = physical activity rating. HR = heart rate. RPE = rating of perceived exertion (15-point scale). RER = respiratory exchange ratio.

Table 3

Descriptive Statistics for Walkers, Joggers, and Runners

	Walker (n = 2)	Jogger (n = 81)	Runner (n = 8)
Age (years)	14.5 ± 1.1	14.9 ± 1.7	15.5 ± 1.5
Height (m)	170.7 ± 4.6	163.6 ± 11.1	168.6 ± 8.5
Body mass (kg)	84.5 ± 15.9	56.3 ± 11.9	61.5 ± 12.5
BMI ($kg \cdot m^{-2}$)	28.8 ± 3.9	20.9 ± 3.5	21.5 ± 3.4
Body Fat (%)	35.0 ± 0.0	21.1 ± 8.5	14.2 ± 5.7
PFA score	5.0 ± 1.4	16.3 ± 4.7	20.4 ± 3.1
PA-R score	3.0 ± 0.0	6.2 ± 2.6	9.1 ± 1.1
<u>Submaximal Exercise Test</u>			
Treadmill speed (mph)	3.7 ± 0.0	5.1 ± 0.5	6.4 ± 0.4
Steady-state HR	158.5 ± 0.7	165.6 ± 12.4	158.9 ± 6.2
% age-predicted maximal HR	76.9 ± 0.2	80.3 ± 6.2	77.5 ± 2.9
RPE	11.0 ± 0.0	12.5 ± 1.7	13.1 ± 2.6
<u>Maximal Exercise Test</u>			
Maximal grade	10.2 ± 3.9	9.7 ± 3.0	10.6 ± 2.5
Maximal HR	198.0 ± 8.5	199.3 ± 6.7	198.9 ± 8.3
% age-predicted maximal HR	96.1 ± 3.5	96.7 ± 3.4	97.0 ± 3.8
Maximal RER	1.09 ± 0.02	1.06 ± 0.06	1.12 ± 0.05
Maximal RPE	17.5 ± 0.7	18.4 ± 1.4	18.9 ± 0.9
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	33.3 ± 3.9	48.4 ± 8.4	58.5 ± 7.0

Note. Participants were categorized as walkers, joggers, or runners based on the treadmill speed that elicited an exercise HR of at least 70% of their age-predicted maximal HR.

Table 4

Regression Equation to Estimate VO_2max from Non-Exercise and Submaximal Exercise Test Data.

Variable	ß	ß-weight	*t* value	*p* value
Intercept	11.201			
Gender (0 = female; 1 = male)	6.877	0.383	5.113	0.0001
Treadmill speed (mph)	3.573	0.263	3.172	0.002
Body mass (kg)	-0.174	-0.245	-3.440	0.001
PFA score	0.405	0.226	3.028	0.003
PA-R score	0.653	0.195	2.698	0.008
Age (years)	1.019	0.187	2.385	0.019
R	0.83			
R^2	0.69			
SEE ($mL\cdot kg^{-1}\cdot min^{-1}$)	5.16			
%SEE (% of VO_2max)	10.51			
R_{PRESS}	0.80			
SEE_{PRESS} ($mL\cdot kg^{-1}\cdot min^{-1}$)	5.37			
$\%SEE_{PRESS}$ (% of VO_2max)	10.94			

Table 5

Regression Equation to Estimate VO_2max from Maximal Exercise Test Data.

Variable	ß	ß-weight	*t* value	*p* value
Intercept	-3.261			
Gender (0 = female; 1 = male)	3.359	0.187	4.42	0.0001
Body mass (kg)	-0.082	-0.115	-3.03	0.0032
Treadmill speed (mph)	7.351	0.541	13.30	0.0001
Treadmill maximal grade (%)	1.750	0.579	14.56	0.0001
R	0.93			
R^2	0.88			
SEE ($mL \cdot kg^{-1} \cdot min^{-1}$)	3.16			
%SEE (% of VO_2max)	6.4			
R_{PRESS}	0.93			
SEE_{PRESS} ($mL \cdot kg^{-1} \cdot min^{-1}$)	3.25			
$\%SEE_{PRESS}$ (% of VO_2max)	6.6			

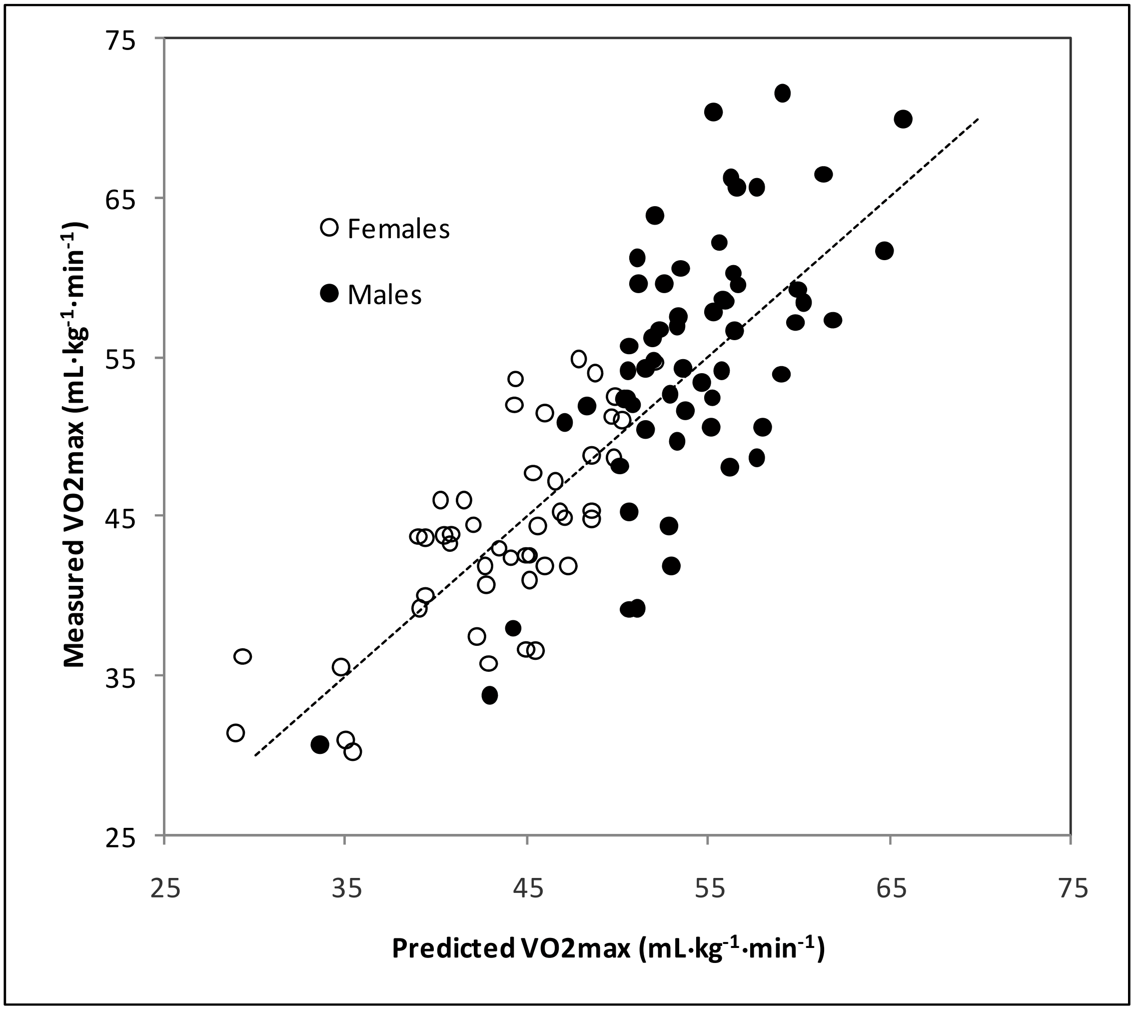

Figure 1

Predicted versus measured VO_2peak in males and females using the N-EX and submaximal exercise data.

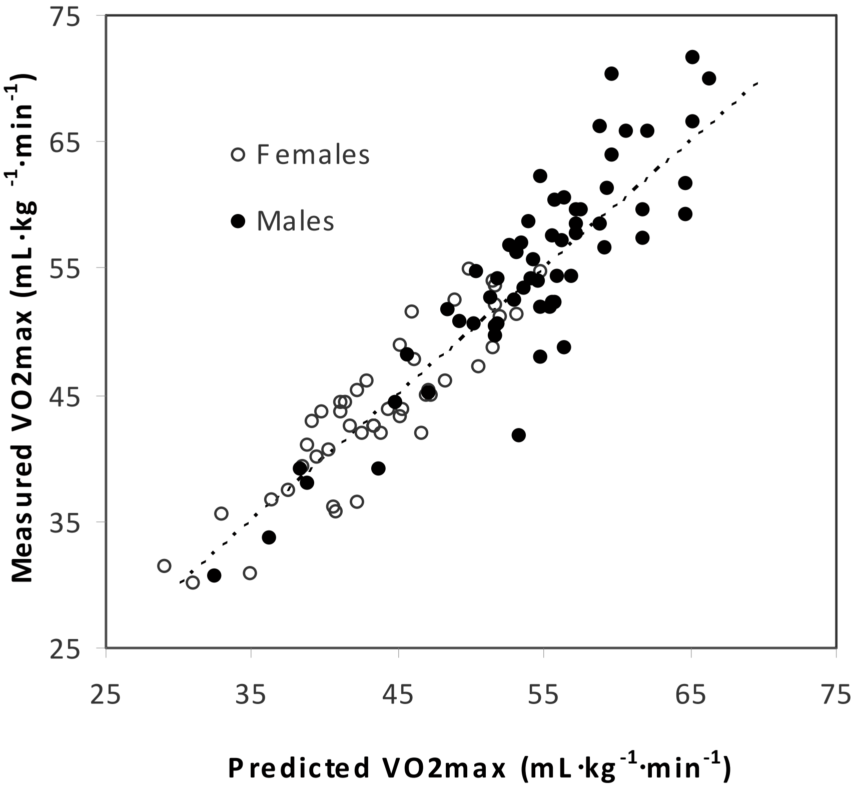

Figure 2

Predicted versus measured VO_2peak in males and females derived from data generated with the maximal exercise test.

Appendix A

Prospectus

Chapter 1

Introduction

Cardiorespiratory fitness is one of the five components of health-related physical fitness. The best measure of cardiorespiratory fitness is maximal oxygen uptake (VO_2max) which is the maximal amount of oxygen that can be utilized during strenuous exercise. VO_2max defines the upper limits of the cardiovascular system's ability to deliver oxygen to active skeletal muscle and the skeletal muscle's ability to use the oxygen in aerobic metabolic pathways for the regeneration of adenosine triphosphate (ATP).

Measurement of VO_2max has become increasingly important for several reasons. In athletes, it is often measured to determine the current level of cardiorespiratory fitness or to assess the effectiveness of a training program. Assessments of cardiorespiratory fitness can be used to (a) educate participants about the current level of physical fitness relative to health-related norms and age-and gender-matched norms; (b) provide information necessary to develop a safe, appropriate, and effective exercise program for individuals who are beginning a physical activity or exercise program, or increasing their current levels of exercise; and (c) motivate participants by establishing reasonable goals to increase physical activity and improve physical fitness. Assessment of cardiorespiratory fitness can also help stratify the risk for cardiovascular disease. Measurement of VO_2max in children and adolescents is performed for many of the same reasons as for adults.

For a maximal VO_2 value measured during an exercise test to be classified as VO_2max, results from the exercise test must satisfy several criteria. The definitive criterion for VO_2max is a plateau in VO_2 despite further increases in work load. In adults, if an exercise test does not elicit a plateau in VO_2 then the maximal VO_2 value may still be considered VO_2max if other criteria are met, otherwise it is termed VO_2peak. Many children may not be able to attain a plateau in VO_2 despite a maximal effort (McMurray, Guion, Ainsworth, & Harrell, 1998). Owing to the difficulties in obtaining VO_2 plateaus in children, (McMurray et al., 1998; Paterson, Cunningham, & Donner, 1981; Rowland & Cunningham, 1992), VO_2peak can be used to approximate VO_2max (Day, Rossiter, Coats, Skasick, & Whipp, 2003; Pitetti, Fernhall, & Figoni, 2002).

Direct measurement of VO_2 requires the use of a metabolic cart and is generally reserved for laboratory settings. Costly equipment and the need for trained personnel to conduct the exercise test, precludes a maximal graded exercise test (GXT) for most children. The reasonable place to assess cardiorespiratory fitness for most children is in a physical education class in the public schools. As a result, many field tests have been developed to estimate VO_2peak in children and adolescents. In general, the tests suffer from lack of direct application to fitness training (e.g., 20 meter shuttle run), require significant motivation for maximal performance (e.g., 1.5-mile run, 1-mile run/walk, 12-minute run), do not account for more than 50% of the shared variance and are therefore weak predictors of cardiorespiratory fitness, or are not applicable to both male and female adolescents (Bonen, Heyward, Cureton, Boileau, & Massey, 1979; McMurray et al., 1998; Metz & Alexander, 1971; Pitetti et al., 2002; Suminski, Ryan, Poston, & Jackson, 2004). Recently, George, Paul, Hyde, Bradshaw, Vehrs, Hager, and Yanowitz (2009) devised a walk-jog-run treadmill protocol to estimate VO_2max in adults. The walk-jog-run protocol is advantageous because it accommodates participants of various fitness levels. The walk-jog-run protocol has not been validated in adolescents.

With the advances in physical education, many schools have treadmills in their physical education or athletic facilities. In addition, many community-based fitness facilities are open to children and adolescents. Based on a review of the literature, it would be advantageous to validate a submaximal treadmill walk-jog-run protocol that can be used to estimate VO_2peak in adolescents 12 to 17 years of age based on age, gender, physical characteristics (e.g., weight, body mass index [BMI, kg/m2]) and physiological responses to exercise (e.g., heart rate) as opposed to performance in timed or distance tests.

Statement of Purpose

The purpose of this study is to develop a regression equation that can be used in conjunction with a submaximal treadmill walk-jog-run test to predict VO_2peak in male and female adolescents 12 to 17 years of age.

Hypotheses

Null Hypothesis: There is no relationship between body weight, BMI, age, gender, and the heart rate response to a self-selected submaximal treadmill walking, jogging, or running speed in male and female adolescents 12 to 17 years of age.

Research Hypothesis: There is a relationship between body weight, BMI, age, gender, and the heart rate response to a self-selected submaximal treadmill walking, jogging, or running speed in male and female adolescents 12 to 17 years of age.

Definition of Terms

Adolescence –The developmental period corresponding to Tanner stages 3 and 4, occurring between childhood and adulthood.

Children – Boys and girls who have not yet developed secondary sex characteristics. In boys, this normally occurs at approximately age 13, whereas in girls, this normally occurs at approximately age 11. This period of development is often referred to as preadolescence.

VO_2max – The greatest amount of oxygen that is consumed during strenuous aerobic exercise, measured during a maximal graded exercise test on the treadmill.

VO_2peak – The greatest amount of oxygen that is consumed during strenuous aerobic exercise that is measured during a mode of exercise that is not weight bearing or that is known not to be maximal.

Assumptions

The 12-17-year-old adolescents of the study group will be representative of other adolescents 12 to 17 years of age.

During the maximal graded exercise tests, each subject will reach a maximal VO_2 value which can be defined as VO_2max or VO_2peak.

Limitations

The prediction equation generated in this study will be applicable for use only with adolescents with physical characteristics similar to the study group.

Chapter 2

Review of Literature

Cardiorespiratory fitness is typically described in terms of maximal ability to consume oxygen during strenuous exercise. Maximal oxygen uptake (VO_2max) defines the upper limits of the cardiovascular system to deliver oxygen to the active skeletal muscle mass and the ability of the skeletal muscle tissue to use the oxygen in aerobic metabolic pathways for the regeneration of adenosine triphosphate (ATP). The Fick equation defines the parameters of oxygen uptake:

$$VO_2 = Q \times \text{av-}O_2 \text{ difference}$$

where, Q = cardiac output, which is the product of stroke volume (SV) and heart rate (HR) and av-O_2 difference = arterio-venous difference, which represents the amount of oxygen (ml) that is used by metabolically active tissues per deciliter of blood flow. During incremental aerobic exercise, HR, SV, Q, arterio-venous oxygen difference, and VO_2 increase until maximal values are attained. The Fick equation can be modified to depict the parameters of VO_2max:

$$VO_2max = Qmax \times \text{av-}O_2 \text{ differencemax}$$

A number of health-related outcomes are influenced by cardiorspiratory fitness level, or VO_2max. Generally, a higher level of cardiorespiratory fitness decreases the risks for cardiovascular disease (CVD), coronary artery disease (CAD), stroke, obesity, and type 2 diabetes. Myers, Prakash, Froelicher, Do, Partington, and Atwood (2002) reported exercise capacity measured in metabolic equivalents (MET) is a more powerful predictor of mortality in adult men than any other recognized risk factors for cardiovascular disease. When other risk factors (i.e., smoking, hypertension, diabetes, obesity, hypercholesterolemia) are present, risk of death increases significantly as cardiorespiratory fitness levels decrease. In the presence of other risk factors, the risk of death from any cause in individuals whose exercise capacity is 5 MET or less is double that of individuals whose exercise capacity is more than 8 MET. Each 1 MET increase in exercise capacity results in a 12% reduction in all cause mortality.

Whereas children seldom exhibit explicit symptoms of CVD, the childhood years provide the genetic-, physiologic-, and lifestyle-related precursors for the development and manifestation of CVD in adulthood (Brooks, Fahey, & Baldwin, 2005; Hickenlooper & Sowan, 1988; Pitetti et al., 2002). Regular assessment of cardiorespiratory fitness in children and adolescents may be warranted at a time when there are increased concerns for physical inactivity- and obesity-related diseases among children and adolescents. An assessment of cardiorespiratory fitness in children and adolescents must require little time and be safe and simple to administer in various settings (e.g., physical education programs and community fitness centers).

Gender Differences in VO2max

Compared to women of the same age, adult men generally have higher absolute (L/min) and relative (mL • kg-1 • min-1) VO_2max values. VO_2max expressed in absolute terms is dependant, in part, on the size of one’s body (Wilmore & Costill, 2004). All else remaining equal, larger people have a larger heart, greater blood volume, and more muscle mass and are thus able to consume a greater total amount of oxygen compared to their smaller counterpart. Compared to women of the same age, the higher VO_2max values in men are generally due to differences in body size, muscle mass, and capacity of the cardiovascular system (Wilmore & Costill, 2004).

Anthropometric and physiologic differences between young boys and girls are not large enough to produce a significant difference in their VO_2peak values. On average, boys and girls are similar in body size, body composition, and VO_2peak (ACSM, 2006; Brooks et al., 2005; Wilmore & Costill, 2004). In general, as children’s body size increases, their VO_2peak values increase due to increases in the size of the heart and lungs, quantity of muscle mass, and vascularization of skeletal muscle tissue (Brooks et al., 2005; Wilmore & Costill, 2004). At the onset of puberty, however, boys’ hearts grow larger than girls’ and boys develop significantly greater muscle mass, whereas girls develop greater fat mass in sex specific fat deposits in the hips, thighs, and breasts (Brooks et al., 2005). In boys, absolute VO_2peak increases until age 18, in girls absolute VO_2peak increases until about 14 to 16 years of age (Plowman, 2001a; Shvartz & Reynolds, 1990). After reaching a maximal value, VO_2max gradually decreases over the age span in both men and women.

The Age-related Decline in VO_2max

Maximal oxygen uptake steadily declines with age (Irving, Kusumi, & Bruce, 1980; Jackson et al., 1995; Jackson et al., 1996; Plowman, Drinkwater, & Horvath, 1979;

Tanaka et al., 1997; Toth, Gardner, Ades, & Poehlman, 1994). The age-related decline in VO_2max is likely due to the combined effects of decreased physical activity, increased adiposity, decreased muscle mass, and a lower maximal HR (Toth et al., 1994). Although an age-related decline in VO_2max is inevitable, the rate of decline can be reduced by maintaining a healthy body composition and remaining physically active through the life-span (Jackson et al., 1995; Jackson et al., 1996; Toth et al., 1994). Fifty percent of the typical age-related decline in VO_2max in men (0.46 mL • kg-1 • min-1 • yr-1) and women (0.54 mL • kg-1 • min-1 • yr-1) is due to age related changes in body composition and physical activity (Jackson et al., 1995; Jackson et al., 1996).

Measuring VO_2max

VO_2 and VO_2max can be measured using a metabolic cart, which includes oxygen and carbon dioxide gas analyzers, a flow meter, heater, expired air mixing chamber and a computer. VO_2max is measured during a maximal GXT on a treadmill. Administering a maximal GXT requires familiarity with the use of a metabolic cart, exercise testing procedures, and normal response to incremental exercise. Due to the cost of equipment and training of exercise testing personnel, maximal GXTs are generally reserved for laboratory or clinical settings.

For a maximal VO_2 value measured during a GXT to be classified as VO_2max, the exercise test must satisfy several objective and subjective criteria (ACSM, 2006). VO_2max is generally characterized by a plateau in VO_2 despite further increases in work load. Additional criteria for establishing a valid VO_2max include (a) a failure of HR to increase with further increases in exercise intensity, (b) a postexercise blood lactate concentration > 8 mmol/L, (c) a respiratory exchange ratio (RER) at test termination > 1.1, (d) HR at test termination > 85% age-predicted HR maximum, and (e) signs of exertional fatigue and a rating of perceived exertion (RPE) > 17 on the 6 to 20 scale (Maud & Foster, 1995). If a testing protocol does meet the criteria for a valid VO_2max test, then the maximal VO_2 value obtained is termed VO_2peak.

Even though exercise tests can be performed in any mode of exercise (e.g., treadmill walking/jogging, leg ergometery, arm ergometry), the highest maximal VO_2 values are attained during weight bearing exercise (e.g., treadmill running). Maximal VO_2 values obtained during leg or arm ergometry are less than those obtained during treadmill running. Therefore, maximal VO_2 values measured during modes of exercise other than the treadmill are referred to as VO_2peak.

VO_2max and VO_2peak in Children and Adolescents

Though some aspects of children's responses to exercise are similar to adults,' children are not simply miniature adults (Plowman, 2001a, 2001b). Although differences exist in the physiological responses to exercise between children and adults, none preclude healthy children from participating in maximal exercise testing (Plowman, 2001a).

Some studies indicate that the VO_2 plateau-based criterion for VO_2max is unreliable for use with children (Fredriksen, Ingjer, Nystad, & Thaulow, 1998; Paterson et al., 1981; Rowland, 1996; Rowland & Cunningham, 1992). A plateau in VO_2 may not occur in many children despite a maximal effort (McMurray et al., 1998). Rowland and Cunningham (1992) suggest that children's inability to attain a plateau in VO_2max may indicate that oxygen uptake is not a limiting factor during strenuous exercise. Paterson et al. (1981) suggest that the difficulties in measuring VO_2max in children could stem from the adherence to an unrealistic VO_2 plateau dogma, testing protocols inappropriate for such a young population, and any physiologic response differences between children and adults during exercise.

During a maximal GXT, children may reach maximal VO_2 values despite the lack of a plateau in VO_2 or the ability to meet any of the other criteria for a valid maximal exercise test (Rowland & Cunningham, 1992). For example, children may not be able to reach a RER = 1.10 (Brooks et al., 2005; Sheehan, Rowland, & Burke, 1987). Some researchers advise that a plateau in VO_2 should not be used as a criterion for establishing VO_2max in children. As a matter of convention, because children and adolescents often do not meet the criteria defining a true VO_2max, maximal oxygen uptake values obtained in children and adolescents during exercise testing are often termed VO_2peak values. For convenience's sake, such an approach will be taken in this study.

Estimating VO_2peak in Children and Adolescents

Due to the disadvantages of performing maximal GXT, a number of field tests have been developed to estimate VO_2peak in children and adolescents. Each test exhibits various advantages and disadvantages. The disadvantage of performance-based field tests (i.e., timed or distance tests) is that performance in such tests is not always indicative of cardiorespiratory fitness. Thus, performance-based tests often result in inaccurate estimates of cardiorespiratory fitness. An underlying assumption of performance-based tests is that participants demonstrate their best, or maximal effort. This is not a feasible or safe expectation for many children. In addition, requiring children to perform at such high intensities may imply that similar forms of exercise are required as part of a physical activity or exercise program to improve or maintain physical fitness. This may discourage future participation in physical activity and exercise. The advantage of performance-based field tests is that large groups of children or adolescents can be tested at the same time with minimal supervision and training without the use of expensive equipment.

The advantage of the submaximal steady-state treadmill walk-jog-run test proposed in this study is it is not based on peak performance. Participants will be able to self-select a walking and jogging speed that is compatible with their current level of fitness and abilities. The prediction of VO_2peak will be based on physical characteristics (e.g., age, gender, weight) and the physiological responses (e.g., HR) to a self-selected jogging speed. By using a moderate intensity exercise, the test promotes an appropriate selection of aerobic exercise intensity that can maintain or improve cardiorespiratory fitness and promote lifelong physical activity.

The 20 meter shuttle run. The 20 meter shuttle run test allows for testing of a large number of children at the same time. Performing this test requires children to run back and forth between two markers set 20 meters apart while keeping pace with a cadence on an audio track. As the cadence quickens over time, the children increase their running pace. Cardiorespiratory fitness is predicted based on the highest cadence that can be maintained. Pitetti et al. (2002) found that two different regression equations for predicting VO_2peak using the 20 meter shuttle run test showed only mild validity when compared to a modified Bruce protocol (Fernhall, Pitetti, Vukovich, Stubbs, Hensen, Winnick, et al. (1998) equation $r = 0.66$, $p < 0.01$; Leger and Lambert (1988) equation $r = 0.57$, $p < 0.01$).

The one-mile walk-run. The one-mile walk-run field test is another method used to predict VO_2peak in children and adolescents (Maud & Foster, 1995). The only equipment needed for this test is a one-mile track or course and a stopwatch. Children and adolescents are instructed to complete the one-mile distance in the shortest possible time. Cureton, Sloniger, O'Bannon, Black, and McCormack (1995) used data collected from 753 males and females ages 8 to 25 years to create an equation to predict VO_2peak from one-mile walk-run performance. The resultant equation used five independent variables (time in minutes, time in minutes squared, age, gender, and BMI) to predict VO_2peak with acceptable validity (SEE = 4.8 mL•kg-1 •min-1; $r = 0.72$).

Though it is useful due to its ease of administration to large numbers of participants, the one-mile walk-run test falls short on a couple of points. Two primary assumptions of the one-mile walk-run test are that performance in the test is predictive of fitness and that the participant performs to be best of his/her ability, both of which are not always the case. Fitness level and motivation are key components of performance. Thus, the one-mile walk-run test is only a measure of actual fitness level in participants who perform their very best.

Hunt, George, Vehrs, Fisher, and Fellingham (2000) developed a 1-mile track jog test to predict VO_2max in fit teenagers. The 1-mile track jog test was designed to overcome the problems of motivation associated with performance tests. Using data collected from 41 males and 42 females, Hunt et al. (2000) created a valid equation to predict VO_2max (Radj = 0.88, SEE = 3.26 mL • kg-1 • min-1) based on gender, body mass, jog time, and heart rate. The protocol, originally designed by George, Vehrs, Allsen, Fellingham, and Fisher (1993), required each subject to jog one mile on an indoor track at a submaximal, self-selected pace. To prevent overexertion, the 1-mile jog time was restricted to = 8.0 min for males and = 9.0 min for females, and exercise HR could not exceed 180 bpm at any time (J.D. George et al., 1993).

Submaximal treadmill exercise tests. Using an intermittent treadmill ergometry protocol, Metz and Alexander (1971) created a regression equation to predict VO_2peak in 12-13-year-old boys (r = 0.701), but the equation required the use of a metabolic cart and gas analyzer and only accounted for approximately 50% of the variance.

In a study using 100 boys ages 7 to 15 years, Bonen et al. (1979) created two regression equations to predict VO_2peak in liters per minute and two in milliliters per kilogram per minute. Two equations (units: L/min, r = 0.95; units: mL • kg-1 • min-1, r = 0.62) required the use of a metabolic cart and gas analyzer and thus prove inconvenient to use in a non-laboratory setting. A third equation (units: mL • kg-1 • min-1, r = 0.52) only accounted for 27% of the variance. The final equation (units: L/min, r = 0.94) showed excellent validity and employed age, height, and weight as dependent variables. However, Bonen et al. (1979) only studied boys of a limited age range. Their equations cannot necessarily be generalized to a female or older population.

Recently, George, Paul, Hyde, Bradshaw, Vehrs, Hager, and Yanowitz (2009) devised a walk-jog-run treadmill protocol and regression equation (R = .94, SEE = 3.09 mL • kg-1 • min-1) for predicting VO_2max in adults (18-65 years old) using gender, age, body mass, self-selected treadmill speed, and non-exercise (N-EX) data. The N-EX data included responses to three questions pertaining to one's perceived functional ability (PFA) to walk, jog, or run one mile and three miles, and one's self-reported physical activity rating (PA-R). George et al. used a PA-R scale modified from Jackson et al. (1990). George et al. reported that PFA is a significant ($p < .001$) independent variable in the prediction of VO_2max even in the presence of gender, age, body mass, and self-selected treadmill speed.

The purpose of George et al. (2009) in developing a walk-jog-run treadmill protocol was to easily accommodate individuals of various cardiorespiratory fitness levels. The protocol initially determines whether the participant walks, jogs, or runs to reach a HR of 70% of his/her age predicted HRmax. The subjects begin by walking (3.0-4.0 mph) for four minutes. If the steady-state HR is less then 70% of age predicted HRmax, the subject then jogs (4.1-6.0 mph) for an additional four minutes. If the steady-state HR is less then 70% of age predicted HRmax, the subject then runs (> 6.0 mph) for an additional four minutes. As soon as the subject reaches 70% of the age predicted HRmax, the initial submaximal treadmill test is terminated. The self-selected speed which elicited 70% of the age predicted HRmax serves as the treadmill speed in the regression equation to predict VO_2max.

To date, the walk-jog-run protocol as described by George et al. (2009) has not been validated in adolescents. Because of its ease of administration, and due to its ability to accommodate individuals of most fitness levels, a submaximal treadmill walk-jog-run protocol for predicting VO_2peak in adolescents would be very useful.

Chapter 3

Methods

Participants

One hundred and twenty participants between 12-17 years of age will be invited to participate in this study. Each age will be represented by an equal number of male (n=10) and female (n=10) participants. Exclusion criteria include any known conditions that may reduce the participants' tolerance to exercise or increase the risk of untoward cardiovascular, pulmonary, or metabolic events during the maximal graded exercised test. A pre-participation questionnaire (see Appendix A) will be completed by a parent of each participant to screen for exclusion criteria.

Prior to the recruitment of participants and the collection of data, this study and its informed consent process will be reviewed and approved by the Institutional Review Board (IRB) for the use of human subjects at Brigham Young University (BYU). Participants will be recruited through flyers sent to faculty and staff at BYU. Participating children will complete an Assent Form and parents of participating children will complete a Parents Permission Form prior to data collection to ensure informed consent (see Appendix B). As an incentive to participate in this study, participating children will receive a Cinemark movie gift certificate each time they participate in this study.

This study will be conducted as part of a large scale children's study which involves two other thesis research projects. All three research projects will be conducted concurrently. There will be an overlap of participants, participant recruitment, organization of data collection, data collection, and data entry. The results of the exercise tests performed in this study will be used as descriptive data for one of the other two studies.

Procedures

Appointments for children to participate in this study will be made with parents. Appointments for the females will be scheduled when they are not menstruating. During the initial contact, parents will confirm that their child(ren) does not have any of the conditions or diseases that may exclude their child from participating. Parents will be instructed to have their child(ren) (a) wear comfortable shorts, shirt, and shoes appropriate for exercise; (b) drink plenty of fluids over the 24-hour period preceding the test to ensure normal hydration prior to testing; (c) refrain from eating food other than water, and from using tobacco, alcohol, and caffeine for at least three hours prior to their appointment, (d) avoid exercise or strenuous physical activity the day of the testing; and (e) get at least 6 to 8 hours of sleep the night before the appointment.

Pre-Exercise Testing Procedures. Participants will report to the Exercise Physiology Lab (121 Richards Building) in the Human Performance Research Center at BYU where they will voluntarily provide informed consent and perform submaximal walk-jog-run test and a maximal graded exercise test (GXT) on the treadmill.

Each participant's height (cm) and weight (kg) will be measured and recorded using a calibrated wall scale to the nearest one-half centimeter and a digital weight scale (Ohaus Model CD-33, Ohaus Corporation, Pine Brook NJ, USA) to the nearest one-tenth of a kilogram, respectively. Body mass index (BMI, kg/m2) will be calculated from measured height and weight values.

Each subject will complete two questionnaires (3 questions) to report their PFA (Appendix C) and PA-R (Appendix D) (George et al., 2009; George, Stone, & Burkett, 1997; Jackson et al., 1990).

Subjects will be familiarized with walking, jogging, and running on a treadmill during the submaximal exercise test component of the procedures.

Exercise Testing. All exercise testing will be performed on a motor-driven treadmill (Model TMX425C, Full Vision, Inc., Newton, KS). Metabolic and ventilatory responses to exercise will be measured using a Truemax 2400 metabolic cart (Consentious Technologies, Sandy, UT). To facilitate the measurement of oxygen consumption throughout the GXT, participants will be fitted with a mouthpiece and a nose clip to aid in measuring expired air. Heart rate will be monitored using a radiotelemetry heart rate monitor (Polar Electro OY, Hong Kong) and rating of perceived exertion (RPE) will be monitored using the Borg 15-point scale (Noble, Borg, & Jacobs, 1983). Prior to each exercise test, the calibration of the flow meter will be checked using a 3-L syringe at five different flow rates. The calibration of the oxygen and carbon dioxide analyzers will be checked using room air and a medical grade calibration gas of known concentrations. The metabolic cart will be programmed to display and print metabolic and ventilatory data every 15 seconds.

Each participant will complete a submaximal treadmill test consisting of three stages corresponding to walking, jogging, and running speeds (3.0-4.0 mph, 4.1-6.0 mph, and > 6.0 mph respectively) (George et al., 2009). Each stage will last 4 min and will be conducted at a level grade. The subject will progress through the three stages until he/she reaches 70% of his/her age predicted maximum HR (220 – age), at which time, the submaximal treadmill test will be terminated. The self-selected treadmill speed which elicited 70% of the age predicted maximum HR will serve as the treadmill speed during the GXT. After the submaximal treadmill test, the participants will rest for 10 minutes before completing the maximal GXT. The walk-jog-run test to determine the self-selected pace for the GXT will be considered the submaximal steady-state treadmill walk-jog-run test. The self-selected jogging speed and corresponding steady-state heart rate will be included as independent variables in the statistical analysis.

Each participant will complete a GXT according to the protocol previously described (George, 1996; George et al., 2009). Participants will walk, jog, or run for three minutes at the self-selected treadmill speed that was previously determined to elicit a HR equivalent to 70% of the age-predicted maximal HR. The treadmill speed will remain constant during the remaining stages of the exercise test as the grade is increased 1.5% each minute until the subject voluntarily terminates the test due to fatigue, despite verbal encouragement. Participants will then perform an active walking cool down period at a self-selected speed at level grade.

The participant's effort will be considered maximal if physical signs suggestive of exhaustion are apparent and at least two of the following three criteria are met: (a) maximal RER > 1.0, (b) no further increase in HR despite an increase in workload or a maximal HR that is no less than 15 beats below age-predicted maximal HR, and (c) leveling off of VO_2 despite an increase in workload.VO2peak will be defined as the highest 30-s averageVO_2 value during the final minutes of the exercise test. Maximal HR will be defined as the highest single HR value recorded during the GXT.

To determine the reliability of the measured VO2peak value, 36 randomly selected participants, 18 boys and 18 girls, will be asked to repeat the maximal GXT on another day.

Statistics

SAS statistical software will be used for all data analyses. An alpha level of $p < 0.05$ will be maintained in all analyses. The measured VO2peak will be entered as the dependent variable and age, gender, body mass, BMI, self-selected treadmill walking/jogging/running speed, steady state HR, PFA, PA-R, and any reasonable two-way interactions will be considered independent variables in a regression analysis to predict VO2peak. A prediction equation will be built using data from a validation group consisting of 80% of the subjects. Twenty percent of the subjects will be randomly selected and held out during the model building phase and used as the cross validation group. When producing an equation to predict outcomes, two criteria should be met with respect to both the validation and the cross validation group. First, when predicted values are fit against actual values of each group, the intercept and slope of the line of best fit should be zero and one, respectively. Second, the coefficients in the prediction equation should be similar when a prediction equation is generated from the validation and cross validation group. This demonstrates that the coefficients are stable across the two groups. Use of a cross validation group assures that the regression equation does not over-fit the data.

References

American College of Sports Medicine. (2006). *ACSM's guidelines for exercise testing and prescription* (7th ed.): Lippincott Williams & Wilkins.

Bonen, A., Heyward, V. H., Cureton, K. J., Boileau, R. A., & Massey, B. H. (1979). Prediction of maximal oxygen uptake in boys, ages 7-15 years. *Medicine and Science in Sports, 11*(1), 24-29.

Brooks, G. A., Fahey, T. D., & Baldwin, K. M. (2005). *Exercise physiology: human bioenergetics and its applications* (4th ed.). New York: McGraw-Hill.

Cureton, K. J., Sloniger, M. A., O'Bannon, J. P., Black, D. M., & McCormack, W. P. (1995). A generalized equation for prediction of VO_2peak from 1-mile run/walk performance. *Medicine and Science in Sports and Exercise, 27*(3), 445-451.

Day, J. R., Rossiter, H. B., Coats, E. M., Skasick, A., & Whipp, B. J. (2003). The maximally attainable VO_2 during exercise in humans: The peak vs. maximum issue. *Journal of Applied Physiology, 95,* 1901-1907.

Fernhall, B., Pitetti, K. H., Vukovich, M. D., Stubbs, N., Hensen, T., Winnick, J. P., et al. (1998). Validation of cardiovascular fitness tests in children with mental retardation. *American Journal on Mental Retardation, 102*(6), 602-612.

Fredriksen, P. M., Ingjer, F., Nystad, W., & Thaulow, E. (1998). Aerobic endurance testing of children and adolescents – A comparison of two treadmill-protocols. *Scandanavian Journal of Medicine & Science in Sports, 8,* 203-207.

George, J. D. (1996). Alternative approach to maximal exercise testing and VO_2max prediction in college students. *Research Quarterly for Exercise and Sport, 67*(4), 452-457.

George, J. D., Paul, S. L., Hyde, A., Bradshaw, D. I., Vehrs, P. R., Hager, R. L., et al. (2009). Prediction of maximum oxygen uptake using both exercise and non-exercise data. *Measurement in Physical Education and Exercise Science, 13*(1), 1-12.

George, J. D., Stone, W. J., & Burkett, L. N. (1997). Non-exercise VO_2max estimation for physically active college students. *Medicine and Science in Sports and Exercise, 29*(3), 415-423.

George, J. D., Vehrs, P. R., Allsen, P. A., Fellingham, G. W., & Fisher, A. G. (1993). VO_2max estimation from a submaximal 1-mile track jog for fit college-aged individuals. *Medicine and Science in Sports and Exercise, 25*, 401-406.

Hickenlooper, G. B., & Sowan, N. A. (1988). Comparison of cardiorespiratory fitness tests for children. *Pediatric Nursing, 14*(485-491).

Hunt, B. R., George, J. D., Vehrs, P. R., Fisher, A. G., & Fellingham, G. W. (2000). Validity of a submaximal 1-mile track jog test in predicting VO_2max in fit teenagers. *Pediatric Exercise Science, 12*, 80-90.

Irving, J. B., Kusumi, F., & Bruce, R. A. (1980). Longitudinal variations in maximal oxygen consumption in healthy men. *Clinical Cardiology, 3*, 134-136.

Jackson, A. S., Beard, E. F., Wier, L. T., Ross, R. M., Stuteville, J. E., & Blair, S. N. (1995). Changes in aerobic power of men, ages 25-70 yr. *Medicine and Science in Sports and Exercise, 27*(1), 113-120.

Jackson, A. S., Blair, S. N., Mahar, M. T., Wier, L. T., Rossand, R. M., & Stuteville, J. E. (1990). Prediction of functional aerobic capacity without exercise testing. *Medicine and Science in Sports and Exercise, 22*(6), 863-870.

Jackson, A. S., Wier, L. T., Ayers, G. W., Beard, E. F., Stuteville, J. E., & Blair, S. N. (1996). Changes in aerobic power of women, ages 20-60 yr. *Medicine and Science in Sports and Exercise, 28*(7), 884-891.

Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*(93-101).

Maud, P. J., & Foster, C. (Eds.). (1995). *Physiological assessment of human fitness*. Champaign: Human Kinetics.

McMurray, R. G., Guion, W. K., Ainsworth, B. E., & Harrell, J. S. (1998). Predicting aerobic power in children. *Journal of Sports Medicine and Physical Fitness, 38*, 227-233.

Metz, K. F., & Alexander, J. F. (1971). Estimation of maximal oxygen uptake from submaximal work parameters. *Research Quarterly, 42*(2), 187-193.

Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S., & Atwood, J. E. (2002). Exercise capacity and mortality among men referred for exercise testing. *New England Journal of Medicine, 346*(11), 793-801.

Noble, B. J., Borg, G. A. V., & Jacobs, I. (1983). A category-ratio perceived exertion scale: Relationship to blood and muscle lactates and heart rate. *Medicine and Science in Sports and Exercise, 15*(523-528).

Paterson, D. H., Cunningham, D. A., & Donner, A. (1981). The effect of different treadmill speeds on the variability of VO_2 max in children. *European Journal of Applied Physiology and Occupational Physiology, 47*, 113-122.

Pitetti, K. H., Fernhall, B., & Figoni, S. (2002). Comparing two regression formulas that predict VO_2peak using the 20-m shuttle run for children and adolescents. *Pediatric Exercise Science, 14*, 125-134.

Plowman, S. A. (2001a). Children aren't miniature adults: Similarities and differences in physiological responses to exercise part 1. *ACSM's Health & Fitness Journal, 5*(5), 11-17.

Plowman, S. A. (2001b). Children aren't miniature adults: Similarities and differences in physiological responses to exercise part 2. *ACSM's Health & Fitness Journal, 5*(6), 13-18.

Plowman, S. A., Drinkwater, B. L., & Horvath, S. M. (1979). Age and aerobic power in women: A longitudinal study. *Journal of Gerontology, 34*(4), 512-520.

Rowland, T. W. (1996). *Developmental exercise physiology*. Champaign: Human Kinetics.

Rowland, T. W., & Cunningham, L. N. (1992). Oxygen uptake plateau during maximal treadmill exercise in children. *Chest, 101*, 485-489.

Sheehan, J. M., Rowland, T. W., & Burke, E. J. (1987). A comparison of four treadmill protocols for determination of maximum oxygen uptake in 10- to 12-year-old boys. *International Journal of Sports Medicine*, *8*, 31-34.

Shvartz, E., & Reynolds, R. C. (1990). Aerobic fitness norms for males and females aged 6 to 75 years: A review. *Aviation, Space, and Environmental Physiology*, *61*, 3-11.

Suminski, R. R., Ryan, N. D., Poston, C. S., & Jackson, A. S. (2004). Measuring aerobic fitness of Hispanic youth 10 to 12 years of age. *International Journal of Sports Medicine, 25*, 61-67.

Tanaka, H., DeSouza, C. A., Jones, P. P., Stevenson, E. T., Davy, K. P., & Seals, D. R. (1997). Greater rate of decline in maximal aerobic capacity with age in physically active vs. sedentary healthy women. *Journal of Applied Physiology, 83*(6), 1947-1953.

Toth, M. J., Gardner, A. W., Ades, P. A., & Poehlman, E. T. (1994). Contribution of body composition and physical activity to age-related decline in peak VO_2 in men and women. *Journal of Applied Physiology, 77*(2), 647-652.

Wilmore, J. H., & Costill, D. L. (2004). *Physiology of sport and exercise* (3rd ed.). Champaign: Human Kinetics.

Appendix A1

Pre-visit Study Description and Screening

Pre-visit Study Description and Screening

The following brief description of the study will be given to parents when they initially call for information and make and appointment.

This study is designed to develop an exercise test that will predict aerobic fitness in teenagers. You must bring your son or daughter to BYU where they will perform a maximal exercise test on the treadmill. Your son and daughter may be asked to repeat the test on another day. Participation in this study will take less than 60 minutes. If your son or daughter wants the results of the test, they will be given to him/her with an explanation of what they mean. Your son or daughter will receive a $5 movie pass for participating in this study. To participate in this study, you son or daughter must:

☐ be between the ages of 12-17

☐ not be receiving treatment for an illness

☐ not be taking medications

☐ not be anemic, bulimic, or anorexic

☐ not be diabetic

☐ not have asthma or other pulmonary diseases

☐ not have symptoms of cardiovascular disease or known disease

☐ not be menstruating

☐ not be pregnant

In order to prepare for the exercise test, we ask that your son or daughter come to their appointment:

☐ having fasted (other than water) for 4 hours

☐ not having exercised (other than normal daily living activities) for 4 hours

☐ wearing gym shorts and lose fitting t-shirt and comfortable gym or running shoes

The informed consent form will be completed during the first visit.

Appendix A2

Pre-Exercise Test Questionnaire

Pre-Exercise Test Questionnaire

The following questions are to be asked of each participant prior to exercise testing. A "yes" response to any of the questions may require rescheduling.

<u>Yes</u> <u>No</u>

Have you eaten in the last 4 hours?

Have you exercised in the last 4 hours?

Are your currently taking any medications?

Are you menstruating?

Have you ever felt pain in your chest during exercise?

Do you have shortness of breath when resting?

Do you experience unusual fatigue or shortness of breath during exercise?

Do you have difficulty breathing when reclined, lying down or sleeping?

Are you diabetic?

Have you ever been diagnosed with anorexia or bullemia?

Are you currently under a doctor's care for any reason?

Have you ever been told not to participate in any particular kind of physical activity?

Have you had any recent injuries?

Have you had any surgeries in the last 6 months?

Appendix A3

Pre-Participation Questionnaire

Pre-Participation Questionnaire

INSTRUCTIONS. Parents, please respond to the following questions on behalf of your child.

Check only one of the boxes (Yes, No) for each question.

Your Child's Name *Your Name* *Date*

Yes No

Has your doctor ever said that your son or daughter has a heart condition and that he/she should only do the types of exercise that your doctor recommends?

Has your son or daughter ever said they feel pain in their chest when they are physically active?

Does your son or daughter lose their balance because of dizziness or does he/she ever lose consciousness?

Does your son or daughter have a bone or joint problem that could be made worse by a change in their physical activity?

Is your son or daughter currently taking medications for any reason?

Is your son or daughter currently receiving any kind of medical treatment for any reason?

Does your son or daughter smoke cigarettes?

Does your son or daughter have shortness of breath when resting?

Does your son or daughter have swelling of the ankles?

Does your son or daughter experience unusual fatigue or shortness of breath with usual activities?

Does your son or daughter have difficulty breathing when reclined, lying down or sleeping?

Has your son or daughter had sensations of rapid or irregular heart beats?

Has your son or daughter ever been told they are diabetic (Type 1 or 2)?

Does your son or daughter have a pacemaker?

Does your son or daughter have asthma or any other lung disease?

Does your son or daughter take insulin?

Does your son or daughter have any condition that you should be seeing, have seen, or are currently seeing a doctor about?

Is your son or daughter anemic?

Has your son or daughter ever been diagnosed with anorexia or bullemia?

Is your son or daughter currently under a doctor's care for any reason?

Has your son or daughter ever been told not to participate in any particular kind of physical activity?

Has your son or daughter had any recent injuries?

Has your son or daughter had any surgeries in the last 6 months?

Do you know of any other reason why your son or daughter should not participate in physical activity or this exercise test?

Appendix A4

Parental permission for a child to participate as a research subject

PARENTAL PERMISSION
FOR A CHILD TO PARTICIPATE AS A RESEARCH SUBJECT

Title: Development of a Submaximal Exercise Test to Predict Cardiorespiratory Fitness in Adolescents

Introduction. The purpose of this research project is to develop a new exercise test that can be used to predict aerobic fitness in youth. Most exercise tests that are currently used predict aerobic fitness based on performance in distance or timed runs that involve strenuous exercise. The new test will involve moderate intensity exercise at a self-selected pace. Pat Vehrs, Ph.D., a faculty member in the Department of Exercise Sciences is conducting this project.

Procedures. Your child has been asked to participate in this study because he/she meets the criteria for participation. Your son or daughter can participate in this study if he/she is 12-17 years of age, is not currently pregnant, menstruating, anorexic, bulimic, anemic, taking medications, or have any diseases or symptoms that may limit his/her tolerance to exercise. You will be asked to complete a Pre-Participation Questionnaire on behalf of your son or daughter that identifies medical reasons that your son or daughter could not safely participate in this study.

As a participant in this research project, your son or daughter will be asked to:

a. Not eat or drink (except water) and avoid exercise for four (4) hours prior to participation
b. Complete a Pre-Exercise Test Questionnaire.
c. Have his/her height and weight measured.
d. Perform a maximal exercise test on the treadmill. The purpose of this test is to determine your son's or daughter's aerobic fitness. This is done by measuring the amount of oxygen he/she can consume during strenuous exercise. This test requires that your son or daughter to wear a nose clip and a mouthpiece which directs expired air to a computerized gas analysis instruments. The mouthpiece fits into the mouth much like a snorkle would. Oxygen consumption is measured during the entire test. Your son or daughter will also wear a heart rate monitor under their shirt. The exercise test begins with walking at a brisk pace for 3 minutes. The speed of the treadmill is then increases to a jogging speed, which is maintained for another 3 minutes. After this, the speed remains the same, but the incline of the treadmill is increased every minute until your son or daughter can no longer keep pace with the treadmill. The test will end due to fatigue. When the test is over, the mouthpiece and nose clip will be removed and your son or daughter will cool-down by walking on the treadmill. This test takes about 15 minutes to complete.

The total amount of time needed to complete this test (including preparation time, the exercise test, and cool down) will be 30-60 minutes. It may take longer if you have to wait for another person to finish a test.

Your son or daughter may be asked to return on another day and repeat the measurements.

Risks and Discomforts. There are minimal, if any, risks and discomforts associated with participating in this study. Because the exercise tests involves strenuous exercise, your son or daughter will be tired at the end of the test. This form of fatigue usually does not last very long. Your son or daughter may have difficulty breathing through the mouthpiece that must be worn during the exercise test. The noseclip will force your son or daughter to breath through their mouth. The risks involved in performing an exercise test such as this are minimal. In adults, the risk of sudden death during a maximal exercise tests is one in a varied population of 20,000. In adults, risks are associated with underlying disease. The risks associated with an exercise test in adolescents is less. Risks will be minimized because only youth that do not have any known pre-existing conditions, diseases, or characteristics that may result in exercise intolerance will be able to participate in this study. The risks associated with a exercise test are also minimized because the test will be administered by an experienced and trained technician.

Benefits. As a benefit from participating in this study, your son or daughter will be given information about the results of the exercise test. Any questions that you have about your results will be explained to you and/or your son or daughter. There are no other direct benefits to you or your son or daughter. Your son's/daughter's participation in this study will advance our understanding of aerobic fitness should be measured, in for example, physical education programs in the public schools.

Confidentiality. All information gathered about your son or daughter during this study will be confidential. Group data obtained from this research project may be published or presented in professional journals and conferences, but individual results and personal information will remain confidential.

Compensation. Your son or daughter will receive one $5 Cinemark movie pass each time he/she participates in this study. The movie pass will be given after the completion of the exercise test. If your son or daughter returns on a second day to repeat the exercise test, he/she will receive a second movie pass.

Participation. Your son's/daughter's participation in this research study is entirely voluntary. You or he/she may chose to not participate at any time. The researcher may terminate your son's or daughter's participation in this study if they are unable to follow instructions, unwilling or unable to complete the test as directed, or if it is difficult to schedule appointments. Your son or daughter may also be told he/she cannot participate or be asked to participate later if certain conditions exist, such as those identified in the Pre-participation Questionnaire.

Questions about the research. If you have questions regarding this study, you may contact Pat Vehrs Ph.D. at 801-422-1626, by email at pat_vehrs@byu.edu or in person in 116B Richards Building.

Questions about your rights as a research participant. If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair by phone at 801-422-6461, in person or by mail at 133 TLRB, Brigham Young University, Provo, UT 84602, or by email at Christopher_Dromey@byu.edu.

I give consent for my child(ren) to participate in this research study.

________________________________ ____

Name of Parent or Guardian *Name(s) of child(ren)*

____ ________________

Signature of Parent or Guardian *Date*

____ ________________

Signature of Principle Investigator or Assistant *Date*

Appendix A5

Subject permission to participate as a research subject

SUBJECT PERMISSION
TO PARTICIPATE AS A RESEARCH SUBJECT

Title: Development of a Submaximal Exercise Test to Predict Cardiorespiratory Fitness in Adolescents

You are being asked to participate in this research study because you are between12-17 years of age. The purpose of this research project is to develop a new exercise test that can be used to predict aerobic fitness in teenagers. Most exercise tests that you might be familiar require strenuous exercise. The new test will involve moderate intensity exercise. Pat Vehrs, Ph.D., a faculty member in the Department of Exercise Sciences is conducting this project.

During this study, you will be asked to:
a. Complete a Pre-Exercise Test Questionnaire.
b. Have your height and weight measured.
c. Perform a maximal exercise test on the treadmill. The purpose of this test is to determine your aerobic fitness. This is done by measuring the amount of oxygen you can consume during strenuous exercise. This test requires that you wear a nose clip and a mouthpiece. The mouthpiece fits into the mouth much like a snorkle would. You will also wear a heart rate monitor under your shirt. The exercise test begins with walking at a brisk pace for 3 minutes followed by jogging for another 3 minutes. After this, the incline of the treadmill is increased every minute until you are too tired to keep pace with the treadmill. The test takes about 15 minutes to finish.

The total amount of time you will be here will be 30-60 minutes.

You may be asked to return on another day to do the test again.

The exercise test involves hard exercise so you will feel tired at the end of the test. You may find it uncomfortable to breath through the mouthpiece you will be wearing. The risks of serious medical emergencies during an exercise test such as this in youth are minimal.

When we are done, we will give you the results of the test and tell you what they mean. All of your personal test results and information will be kept confidential.

You will receive one $5 Cinemark movie pass each time you finish the exercise test. If you come back on a second day to repeat the test, you will get one more movie pass.

Your participation in this research study is entirely voluntary. You can chose not to participate or stop participating at any time.

If you have questions regarding this study, you may contact Pat Vehrs Ph.D. at 801-422-1626, by email at pat_vehrs@byu.edu or in person in 116B Richards Building.

If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair by phone at 801-422-6461, in person or by mail at 133 TLRB, Brigham Young University, Provo, UT 84602, or by email at Christopher_Dromey@byu.edu.

I voluntarily consent to participate in this research study.

________________________________ _________________

Name *Date*

____________________________________ _________________

Signature of Principle Investigator or Assistant *Date*

Appendix A6

Perceived Functional Ability (PFA) Questions

Perceived Functional Ability (PFA) Questions

1. Suppose you were going to exercise on an indoor track for 1-mile. Which exercise pace is just right for you—not too easy and not too hard?

   Circle the number that most accurately describes your current ability (any number, 1 to 13).

   1 Walking at a slow pace (18 minutes per mile or more)
   2
   3 Walking at a medium pace (16 minutes per mile)
   4
   5 Walking at a fast pace (14 minutes per mile)
   6
   7 Jogging at a slow pace (12 minutes per mile)
   8
   9 Jogging at a medium pace (10 minutes per mile)
   10
   11 Jogging at a fast pace (8 minutes per mile)
   12
   13 Running at a fast, competitive pace (7 minutes per mile or less)

2. How fast could you cover a distance of 3-miles and NOT become breathless or overly fatigued? Be realistic.

   Circle the number that most accurately describes your current ability (any number, 1 to 13).

   1 I could walk the entire distance at a slow pace (18 minutes per mile or more)
   2
   3 I could walk the entire distance at a medium pace (16 minutes per mile)
   4
   5 I could walk the entire distance at a fast pace (14 minutes per mile)
   6
   7 I could jog the entire distance at a slow pace (12 minutes per mile)
   8
   9 I could jog the entire distance at a medium pace (10 minutes per mile)
   10
   11 I could jog the entire distance at a fast pace (8 minutes per mile)
   12
   13 I could run the entire distance at a fast, competitive pace (7 minutes per mile or less)

Source: Modified from George et al., (1997). Non-exercise VO_{2max} estimation for physically active college students. *Medicine and Science in Sports and Exercise*, *29(3)*, 415–423.

Appendix A7

Physical Activity Rating (PA-R)

Physical Activity Rating (PA-R)

INSTRUCTIONS. Pick a number (1 through 10) that best describes how much physical activity you do each week.

	STEP 1 Pick the amount of physical activity you do each week.	STEP 2 This is your PA-R
I avoid physical activity	**AVOID WALKING OR EXERTION.** Example. I always use the elevator and prefer not to exercise.	0
I am not very active	**WALK FOR PLEASURE** Example. I usually use the stairs and occasionally exercise.	1
	MODERATE INTENSITY PHYSICAL ACTIVITY Examples. Walking, golf, weight lifting, tennis, bowling, yard work, calisthenics (pushups, situps, pullups), chores.	
	10-60 min/week	2
	More than 60 min/week	3
	VIGOROUS OR INTENSE PHYSICAL ACTIVITY Examples. Jogging, running, bicycling, swimming rowing, aerobics, soccer, basketball, tennis, racquetball, handball, or other comparable activities.	
	Jog or Run less than 1 mile or 30 min/week	4
	Jog or Run 1-5 miles or 30-60 min/week	5
	Jog or Run 5-10 miles or 1-3 hrs/week	6
I am very physically active	Jog or Run 10-15 miles or 3-6 hrs/week	7
	Jog or Run 15-20 miles or 6-7 hrs/week	8
	Jog or Run 20-25 miles or 7-8 hrs/week	9
	Jog or Run 25+ miles or 8+ hours/week	10