2009-08-05

Predicting VO2max in College-Aged Participants Using Cycle Ergometry and Nonexercise Measures

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PREDICTING VO$_{2MAX}$ IN COLLEGE-AGED PARTICIPANTS USING

CYCLE ERGOMETRY AND NONEXERCISE MEASURES

by

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A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise Sciences

Brigham Young University

December 2009

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

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ABSTRACT

PREDICTING VO$_{2MAX}$ IN COLLEGE-AGED PARTICIPANTS USING

CYCLE ERGOMETRY AND NONEXERCISE MEASURES

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The purpose of this study was to develop a multiple linear regression model to predict treadmill VO$_{2max}$ scores using both exercise and nonexercise data. One hundred five college-aged participants (53 male, 52 female, mean age 23.5 ± 2.8 yrs) successfully completed a submaximal cycle ergometer test and a maximal graded exercise test (GXT) on a motorized treadmill. The submaximal cycle protocol required participants to achieve a steady-state heart rate (HR) equal to at least 70% of age-predicted maximum HR (220-age), while the maximal treadmill GXT required participants to exercise to volitional fatigue. Relevant submaximal cycle ergometer test data included a mean (± SD) ending steady-state HR and ending workrate equal to 164.2 ± 13.0 and 115.3 ± 27.0, respectively. Relevant nonexercise data included a mean (± SD) body mass (kg), perceived functional ability [PFA] score, and physical activity rating [PA-R] score of 74.2 ± 15.1, 15.7 ± 4.3, and 4.7 ± 2.1, respectively. Multiple linear regression was used

to generate the following prediction of cardiorespiratory fitness ($R = 0.91$, $SEE = 3.36$ ml·kg^{-1}·min^{-1}): $VO_{2max} = 54.513 + 9.752$ (gender, 1 = male, 0 = female) – 0.297 (body mass, kg) + 0.739 (PFA, 2-26) + 0.077 (work rate, watts) – 0.072 (steady-state HR). Each predictor variable was statistically significant ($p < .05$) with beta weights for gender, body mass, PFA, exercise workrate, and steady-state HR equal to 0.594, -0.544, 0.388, 0.305, and -0.116, respectively. The predicted residual sums of squares (PRESS) statistics reflected minimal shrinkage ($R_{PRESS} = 0.90$, $SEE_{PRESS} = 3.56$ ml·kg^{-1}·min^{-1}) for the multiple linear regression model. In summary, the submaximal cycle ergometer protocol and accompanying prediction model yield relatively accurate VO_{2max} estimates in healthy college-aged participants using both exercise and nonexercise data.

Key Terms: cycle ergometry, exercise testing, VO_{2max} prediction, nonexercise

ACKNOWLEDGMENTS

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PREDICTING VO$_{2MAX}$ IN COLLEGE-AGED PARTICIPANTS USING

CYCLE ERGOMETRY AND PERCEIVED FUNCTIONAL ABILITY

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Abstract

The purpose of this study was to develop a multiple linear regression model to predict treadmill VO_{2max} scores using both exercise and nonexercise data. One hundred five college-aged participants (53 male, 52 female, mean age 23.5 ± 2.8 yrs) successfully completed a submaximal cycle ergometer test and a maximal graded exercise test (GXT) on a motorized treadmill. The submaximal cycle protocol required participants to achieve a steady-state heart rate (HR) equal to at least 70% of age-predicted maximum HR (220-age), while the maximal treadmill GXT required participants to exercise to volitional fatigue. Relevant submaximal cycle ergometer test data included a mean ($\pm$ SD) ending steady-state HR and ending workrate equal to 164.2 ± 13.0 and 115.3 ± 27.0, respectively. Relevant nonexercise data included a mean ($\pm$ SD) body mass (kg), perceived functional ability [PFA] score, and physical activity rating [PA-R] score of 74.2 ± 15.1, 15.7 ± 4.3, and 4.7 ± 2.1, respectively. Multiple linear regression was used to generate the following prediction of cardiorespiratory fitness ($R = 0.91$, $SEE = 3.36$ ml·kg^{-1}·min^{-1}): $VO_{2max} = 54.513 + 9.752$ (gender, 1 = male, 0 = female) $- 0.297$ (body mass, kg) $+ 0.739$ (PFA, 2-26) $+ 0.077$ (work rate, watts) $- 0.072$ (steady-state HR). Each predictor variable was statistically significant ($p < .05$) with beta weights for gender, body mass, PFA, exercise workrate, and steady-state HR equal to 0.594, -0.544, 0.388, 0.305, and -0.116, respectively. The predicted residual sums of squares (PRESS) statistics reflected minimal shrinkage ($R_{PRESS} = 0.90$, $SEE_{PRESS} = 3.56$ ml·kg^{-1}·min^{-1}) for

the multiple linear regression model. In summary, the submaximal cycle ergometer protocol and accompanying prediction model yield relatively accurate VO_{2max} estimates in healthy college-aged participants using both exercise and nonexercise data.

Key Terms: cycle ergometry, exercise testing, VO_{2max} prediction, nonexercise

Introduction

The criterion measure of cardiorespiratory fitness (CRF) is a person's maximal

oxygen uptake (VO_{2max}; American College of Sports Medicine, ACSM, 2010). VO_{2max} is

measured during a maximal graded exercise test (GXT) and requires highly trained

technicians to administer the test, expensive equipment, and, in some situations, a

physician to oversee the test in case of a medical emergency. VO_{2max} can also be

estimated using a variety of methods involving maximal or submaximal exercise tests, or

nonexercise questionnaires. Submaximal tests have certain advantages over maximal

tests in that specialized lab equipment is unnecessary, test administrators require less

training, and the exercise intensity is realistic for most participants. Submaximal testing

is a popular and effective way of evaluating CRF and is valuable in developing

individualized exercise programs. In addition, periodic submaximal testing provides a

convenient way to monitor progress throughout an exercise program and educates

participants about their potential risk for cardiovascular and other chronic diseases

(ACSM, 2010; Milani, Lavie, Mehra, & Ventura, 2006). Nonexercise methods of

predicting VO_{2max} are also useful and convenient, requiring participants to simply answer

a few questions and then compute a relatively accurate VO_{2max} score using a multiple

linear regression equation (Heil, Freedson, Ahlquist, Price, & Rippe, 1995).

Sjostrand (1947) and Astrand and Ryhming (1954) were the first to develop

submaximal cycle ergometer protocols. Since then, researchers have continued to

develop methods of predicting VO_{2max} from submaximal workloads using cycle

ergometers (ACSM, 2010; Astrand & Ryhming, 1954; George, Vehrs, Babcock, Etchie,

Chinevere, & Fellingham, 2000; Golding, 2000; Leger, Fargeas, VanPraagh,

Ricci,Hooper, & Gagnon, 1992; Sjostrand, 1947; Swain & Wright, 1997; Swank,

Serapiglia, Funk, Adams, Durham, & Berning, 2001). Cycle ergometry is an appealing

mode of testing (as opposed to testing using treadmills or stepping benches) in that 1)

cycle ergometry allows for the selection of precise workrates which can be expressed

with appropriate units of power (e.g., $kgm \cdot min^{-1}$); 2) cycle ergometers require minimal

space and are easy to transport; 3) cycle ergometer exercise is a nonweight-bearing

activity that is usually well tolerated by individuals with orthopedic or other physical

limitations; and 4) heart rate (HR), blood pressure, and electrocardiographic data are

easily collected during the test protocol. In addition, submaximal cycle ergometer tests

provide relatively accurate estimates of CRF in a variety of populations (Fox, 1973;

George et al., 2000; George, Paul, Hyde, Bradshaw, Vehrs, & Hager, 2009; Golding,

Meyers, & Sinning, 1989; Kasch, 1984; Latin & Berg, 1998; Siconolfi, Cullinane,

Carleton, & Thompson, 1982).

However, there are also some limitations to submaximal cycle ergometer testing.

The first is the incongruity among researchers about the best method of predicting VO_{2max}

from a submaximal cycle ergometer test. The Astrand and Ryhming (1954) method uses

a nomogram based on gender, power output, and exercise HR. On the other hand, the

YMCA protocol (Golding, 2000) employs a method where the HR response is plotted

against corresponding submaximal workloads which are then extrapolated to the age-

predicted maximum HR (220-age), maximal workload, and VO_{2max}. The American

College of Sports Medicine continues to recommend the use of the Astrand & Ryhming

nomogram and the YMCA's method of predicting VO_{2max} in their current Guidelines book (ACSM, 2010). Certainly, these methods have provided a convenient and somewhat accurate system for estimating VO_{2max}, but with the advent of computers and programmable calculators, these methods are now antiquated and the use of a multiple linear regression equation to predict VO_{2max} is more appropriate and precise (Arts, Kuipers, Jeukendrup, & Saris, 1993; Ebbeling, Ward, Puleo, Widrick, & Rippe, 1991; George et al., 2009; Hartung, Blancq, Lally, & Krock, 1995; Jessup, Tolson, & Terry, 1974; Leger et al., 1992; Mastropaolo, 1970; Mertens, Kavanagh, & Shephard, 1994; Montoye, Ayen, & Washburn, 1986; Stanforth, Ruthven, Gagnon, Bouchard, Leon, Raon, et al., 1999). Although there are a number of VO_{2max} regression equations available for use, there is an ongoing need to improve the predictive accuracy of these equations.

A second potential limitation of submaximal cycle ergometer testing is that in untrained samples, VO_{2max} measured on a cycle ergometer has been shown to be 3%– 29% lower than the VO_{2max} values measured on a treadmill (Bassett & Boulay, 2000; Beasley, Plowman, & Fernhall, 1989; Davies, 1968; Greiwe, Kaminsky, Whaley, & Dwyer, 1995; Hartung, Krock, Crandall, Bisson, & Myhre, 1993; Hermansen & Saltin, 1969; Lockwood, Yoder, & Deuster, 1997; McKay & Banister, 1976; Swain & Wright, 1997). This is due to the fact that cycling is a nonweight-bearing activity so less muscle mass is required during the exercise. (Because of this, VO_{2max} is often referred to as VO_{2peak} when oxygen uptake is measured during a maximal cycle ergometer test.) In the United States, healthy adults do not commonly exercise on bicycles, which, as shown in

the previously cited studies, may lead to lower VO_{2peak} scores when using a cycle ergometer to elicit VO_{2peak} (since a lower maximal work rate is attained). In addition, field tests such as the Rockport Fitness Walking Test (Kline, Porcari, Hintermeister, Freedson, Ward, & McCarron, 1987) and the YMCA Step Test (Kasch Step Test; Golding, 2000) predict VO_{2max} based on regression equations that use measured VO_{2max} (derived from a maximal treadmill GXT) as the dependent variable. Thus, to maintain consistency it is important that in healthy adults, treadmill VO_{2max} data be used instead of cycle ergometer VO_{2peak} data to generate the VO_{2max} regression equations. This would decrease the probability of under-predicting VO_{2max} when using field tests to estimate VO_{2max}.

A final concern of cycle ergometry is the pedal rate traditionally used during testing. To date, most submaximal tests employ a pedal rate of 50 rpm (ACSM, 2010; Astrand & Ryhming, 1954; Golding, 2000, Hartung et al. 1993). It is speculated that a pedal rate of 50 rpm was adopted to accommodate less-fit individuals or to simplify the power output calculations. However, others have indicated that pedal rates of 50 or 80 rpm (Swain & Wright, 1997), 60 or 80 rpm (Coast, Cox, & Welch, 1986), and 80 or 100 rpm (McKay & Banister, 1976) are valid when predicting VO_{2max} using submaximal cycle ergometers. Although slower pedal rates appear favorable for lower fit individuals, a faster pedal cadence may reduce quadriceps fatigue in higher fit populations by decreasing the inertial resistance a person is working against (Banister & Jackson, 1967; McKay & Banister, 1976). For example, when working at the same resistance (1.0 kp) the workrates can vary greatly with differing pedal cadences (McKay & Banister; e.g.,

1.0 kp · 70 rpm·6m/rev = 420 kpm/min as opposed to 1.0 kp · 50 rpm·6m/rev = 300

kpm/min). Moreover, using a faster pedal cadence has been shown to be more

economical and it is often times preferred by those familiar with cycling (Coast et al;

Hagberg, Mullin, Giese, & Spitznagel, 1981; McKay & Banister; Swain & Wright).

Recently, George et al. (2000) developed a submaximal cycle ergometer protocol

involving 172 participants (18–39 yrs), that overcomes some of the concerns of

traditional submaximal cycle ergometry. For example, the prediction equation was

developed using treadmill VO_{2max} as the dependent variable, and a faster test pedal

cadence of 70 rpm. The workrate progression was determined by the individual's gender,

body mass, and exercise HR response to the warm-up workload. A relatively accurate

VO_{2max} regression equation was developed ($R = .88$, $SEE = 3.12$ ml·kg^{-1}·min^{-1}, $R_{PRESS} =$

0.87, SEE_{PRESS} 3.24 ml·kg^{-1}·min^{-1}) using gender, age, body mass (kg), power output

(watts), and exercise HR as predictor variables. In addition, participants appeared to

respond well to the overall testing experience.

Several nonexercise prediction models have also been developed to predict

VO_{2max}. Nonexercise methods do not require participants to exercise, and employ

questionnaire data in conjunction with other predictor variables such as gender, age,

height, and body mass to predict VO_{2max}. Recent studies used questionnaire data

including two perceived functional ability (PFA; George, Stone, & Burkett, 1997)

questions and one physical activity rating (PA-R; Jackson, Blair, Mahar, Wier, Ross, &

Stuteville, 1990) question. The PFA questions are designed to determine how fast

participants believe they could walk, jog, or run a one and a three mile distance without

becoming overly breathless or fatigued. The sum of the responses to the two PFA

questions is the PFA score (range = 2–26). The PA-R question allows participants to

self-report their level of physical activity during the past six months. The response to the

PA-R question is the PA-R score (range = 0–10). Recent studies have generated

acceptable VO_{2max} predictions (R = 0.81–0.94, SEE = 3.09–5.35 ml·kg^{-1}·min^{-1}) when

employing the PFA and PA-R scores in nonexercise regression models (Bradshaw,

George, Hyde, LaMonte, Vehrs, Hager, & Yanowitz, 2005, George et al., 1997; George

et al., 2009).

The purposes of this study were to refine the submaximal cycle ergometer test

protocol developed by George et al. (2000) and to generate an accurate prediction model

that combines appropriate exercise data (e.g., exercise HR and exercise work rate) and

nonexercise data (e.g., gender, body mass, PFA and PA-R) to predict treadmill derived

VO_{2max}. In addition, minor modifications to the Brigham Young University (BYU)

submaximal cycle ergometer protocol developed by George et al. (2000) will be

evaluated.

<div align="center">Methods</div>

Participants and Procedures

One hundred and nineteen college-aged male and female participants 19-29 years

(53 male, 52 female, mean age 23.5 ± 2.8 yrs), consisting of mostly Caucasians (90%)

were recruited from BYU and surrounding areas. Exercise testing included a modified

version of the BYU submaximal cycle ergometer protocol (George et al., 2000) and the

Arizona State University (ASU) maximal treadmill GXT (George, 1996). Participants

were instructed to drink plenty of water and avoid vigorous exercise the day of testing,

and not to consume food, alcohol, caffeine, or tobacco products three hours before testing

(ACSM, 2010). Each participant was fitted with a HR monitor (Polar, Lake Success,

NY) to measure exercise HR during the submaximal cycle ergometer protocol and the

maximal GXT. Participants' body mass and height were measured and recorded using a

calibrated digital weight scale (Ohaus Model CD-33, Ohaus Corporation, Pine Brook, NJ,

USA) and a wall mounted stadiometer (with participants wearing light exercise clothing

and no shoes). Before data collection, participants were given a brief explanation of all

test protocols, signed a written informed consent document, completed the Physical

Activity Readiness Questionnaire (PAR-Q), the two PFA questions, and the PA-R

question. All methods and procedures of the study were approved by the BYU

Institutional Review Board for Human Subjects.

Data Collection and Analysis

      Modified BYU submaximal cycle ergometer protocol. To prepare for the

submaximal cycle ergometer protocol (George, et al., 2000), the seat height of the cycle

ergometer (Ergomedic 894E, Monark, Sweden) was adjusted so participants' knees had

an approximate five degree bend (with a given pedal in the down position). During the

test, the cycle workload was adjusted by inserting small weight plates (0.5 or 1.0 kg) into

a metal basket (1.0 kg) designed to add resistance to the strap surrounding the cycle's

flywheel. Participants maintained a pedal cadence of 70 rpm throughout the test by

pedaling in sync with an electronic metronome and by referring to a visual display on the

cycle ergometer. The objective of the test was for participants to complete one, two, or

three exercise stages with an ending stage steady-state HR that was at or above 70% of age-predicted maximum HR, ideally without exceeding 85% of maximum age-predicted HR. Steady-state HR was defined as two consecutive HR measurements, within 5 bpm, measured one minute apart (ACSM, 2010).

The submaximal cycle ergometer protocol (see Figure 1) began with a two minute warm-up at a workload of 1.0 kp (420 kpm/min = 70 rev/min · 1.0 kp · 6 m/rev). Heart rate was recorded at the end of the warm-up, which, along with gender and body mass, determined the workload for Stage 1. For example, if the warm-up HR was above 60% of age-predicted maximum HR, the workload remained at 1.0 kp (420 kpm·min^{-1}) for an additional 1-2 minutes which then counted as Stage 1. If the warm-up HR was below 60% of age-predicted maximum HR for any female, and any male weighing less than 73.0 kg, the workload was increased to 1.5 kp (630 kpm·min^{-1}) for Stage 1. For any male, 73.0 kg or above, who had an exercise HR of less than 60% of age-predicted maximum HR, the workload increased to 2.0 kp (840 kpm·min^{-1}) for Stage 1. For Stage 2, the workload was increased by 0.5 kp (210 kpm·min^{-1}) for all participants. At the end of Stage 2, if steady-state HR did not reach 70% of the age-predicted maximum HR, then the workload was increased by 0.5 kp (210 kpm·min^{-1}) and participants completed a final stage. At the conclusion of the participants' final stage (when steady-state HR reached 70% or above), an overall rating of perceived exertion (RPE; 15-point scale; Borg, 1982) was recorded, along with a RPE score for the quadriceps. The maximum HR and workload (watts) were recorded from the final stage. To cool down, participants pedaled at a slow pace for 5–10 minutes until their recovery HR was below 120 bpm.

ASU maximal graded exercise test. After completing the modified BYU submaximal cycle ergometer protocol, participants rested for 10–15 minutes during which time the ASU maximal GXT protocol (George, 1996, George, Bradshaw, Hyde, Vehrs, & Hager, 2007) was explained. Before testing, the flow meter was calibrated using a three liter syringe at five different flow rates. The oxygen and carbon dioxide analyzers were calibrated using room air and a mixture of medical grade gas of known concentrations. During this test, VO_2 was measured using a metabolic cart (ParvoMedic TrueOne 2400, Consentius Technologies, Sandy, UT). VO_2 and respiratory exchange ratio (RER) data were measured continuously, averaged, and printed every 15 seconds.

To warm up for the maximal GXT, participants initially walked on a treadmill (Track Master TMX425C, Full Vision, Inc., Newton, KS) at a level grade while maintaining a comfortable pace. After the first minute, participants chose a walking (3.0 – 4.0 mph), jogging (4.1 – 6.0 mph), or running (> 6.0 mph) (George et al., 2009) pace that they could conceivably maintain for 20 to 30 minutes based on their current fitness level. Once this pace was attained it was maintained throughout the test until the cool down. Following the warm-up, the treadmill grade was increased to 1.5% for Stage 1, and for each subsequent 1minute stage, until participants achieved volitional fatigue and were unable to continue despite verbal encouragement. The self-selected treadmill speed (mph) and the final treadmill grade (%; sustained for a full minute before exhaustion) was recorded along with the participants' maximum RPE and HR. To cool down, participants walked at a slow pace for 5–10 minutes until their recovery HR was below 120 bpm.

After the maximal GXT, the four highest consecutive 15-second VO_2 scores near

the end of the GXT were averaged to compute VO_{2max}. To be considered a valid

maximal test, at least two of the following three criteria were met (ACSM, 2010;

Ebbeling et al., 1991; Howley, Bassett, & Welch, 1995):

1. Maximum HR within 15 beats of age-predicted maximal heart rate (220-age)

2. RER equal to or greater than 1.10

3. No increase in VO_2 with an increase in workload.

Statistics

All data were analyzed using SAS statistical software (SAS 9.1, SAS Institute,

Inc., Cary, NC) with a level of significance set at $p < 0.05$. Stepwise regression was used

to determine the statistical strength and contribution of possible independent variables

(e.g., age, gender, body mass, race, height, body mass index (BMI), final stage exercise

HR, final stage exercise work rate, the PFA score [equaling the sum of the two questions,

2–26], and the PA-R score) in the prediction of VO_{2max}. A multiple linear regression

equation was then generated using those independent variables that provided the most

accurate VO_{2max} prediction. To assess the predictive accuracy of the regression equation,

correlation coefficients (*R* values) and standard error of estimates (*SEE*) were computed.

To account for possible shrinkage when using the prediction equation on independent but

similar samples, predicted residual sums of squares (PRESS) statistics were also

calculated (Holiday, Ballard, & McKeown, 1995).

Three paired *t* test analyses were also employed to cross validate three existing

VO_{2max} prediction equations using the data collected in the current study. These multiple

linear regression equations included the George et al. (2000) submaximal cycle ergometer equation, the George et al. (1996) GXT equation, the Bradshaw et al. (2005), nonexercise prediction equation.

Results

Of the 119 participants who were recruited for the study, 105 participants successfully completed all study requirements. Descriptive statistics, along with submaximal and maximum exercise data are presented in Table 1. Mean VO_{2max}, RER_{max}, and HR_{max} values (±SD) equaled 44.88 ± 8.24 ml·kg^{-1}·min^{-1}, 1.15 ± 0.06, and 191.9 ± 8.1, respectively, indicating that participants achieved maximal levels of exertion. Of the 14 participants who were dropped from the study, 11 failed to satisfy the VO_{2max} maximal exertion criteria, and 3 were dropped because they achieved a VO_{2max} score that was unusually low (< 25 ml·kg^{-1}·min^{-1}) or high (> 65 ml·kg^{-1}·min^{-1}).

Multiple linear regression generated the following regression equation ($R = 0.91$, $SEE = 3.36$ ml·kg^{-1}·min^{-1}, $R_{PRESS} = 0.90$, $SEE_{PRESS} = 3.56$ ml·kg^{-1}·min^{-1}): $VO_{2max} = 54.513 + 9.752$ (gender, $1 =$ male, $0 =$ female) $- 0.297$ (kg) $+ 0.739$ (PFA score) $+ 0.077$ (watts) $- 0.072$ (HR). Each predictor variable was significant ($p < 0.05$) in predicting VO_{2max} and the resulting regression equation accounted for 83.3% of the shared variance of measured VO_{2max}.

The paired t test analyses, used to cross validate the three existing prediction equations, indicated no prediction bias for the maximal GXT equation (George, 1996; mean difference $= -0.21$ ml·kg^{-1}·min^{-1}, $p = 0.50$) or the nonexercise equation (Bradshaw et al., 2005; mean difference $= +0.36$ ml·kg^{-1}·min^{-1}, $p = 0.42$), but did reflect a prediction

bias for the submaximal cycle ergometer equation (George et al., 2000; mean difference = +4.87·kg^{-1}·min^{-1}, p = < 0.0001).

Discussion

The most compelling finding of this study was the statistically significant contribution of the PFA score in the prediction of VO$_{2max}$ using a multiple linear regression model involving cycle ergometry. As an indication of predictive strength, the beta weights (see Table 2) reveal the rank order of the model's independent variables: gender (0.594), body mass (-0.544), PFA (0.388), exercise watts (0.305), and exercise HR (0.116); with a greater contribution from the PFA variable than either of the two exercise-based variables. When the PFA variable is removed from the full model, the explained variance of the regression model drops 10.1% (from 83.3% to 73.2%), the R value decreases from 0.91 to 0.86, and the SEE-value increases from 3.36 ml·kg^{-1}·min^{-1} to 4.26 ml·kg^{-1}·min^{-1}. This suggests that participants' perceived functional ability accounts for a unique portion of the variance beyond that of what standard exercise data (cycle workrate and exercise HR) can explain, and underscores the importance of using the PFA score in the model. Evidently, the PFA data provide a broader, more precise explanation of a person's CRF than can be ascertained by a single fitness test involving submaximal exercise.

In the Stepwise regression analysis, both the PFA and the PA-R scores were evaluated as possible predictor variables in the multiple linear regression model, yet only the PFA score was found to be statistically significant ($p < 0.0001$). We expected the PA-R data to contribute to the VO$_{2max}$ regression model since other studies have included

this variable as a statistically significant variable (Bradshaw et al., 2005; George et al., 2009; George et al., 1997; Jackson et al., 1990) and face validity suggests that the higher one's level of physical activity (up to a point), the greater will be the cardiorespiratory adaptation of the body and the concomitant increase in VO_{2max}. However, the relatively homogenous sample employed in this study with respect to PA-R scores (mean = 4.7 ± 2.1; range = 0 to 10) may be another reason as to why it was limited in predicting VO_{2max}. Nonetheless, since the PA-R variable is included in other age-generalized regression models and because it serves as a useful educational reminder for participants to become more physically active, we generated an additional regression equation for those professionals who may find it useful when administering fitness tests in health and fitness programs (R= 0.91, SEE = 3.35 ml·kg^{-1}·min^{-1}): VO_{2max} = 53.87 + (10.06 x gender; 0 = female, 1 = male) – (0.29 x body mass in kg) + (0.70 x PFA score) + (0.17 x PA-R score) + (0.0749 x exercise watts) – (0.0678 x steady-state HR).

The ACSM and the YMCA both promote using either the extrapolation method or a nomogram to estimate VO_{2max} from submaximal workloads and steady-state HR. To evaluate the accuracy of the extrapolation method, we identified those participants (n = 92) who completed at least two stages of the submaximal cycle ergometer protocol. Then, using the published graph provided by the YMCA (Golding, 2000), we penciled in two data points based on the two steady-state HR and the corresponding submaximal workrates (from two separate stages of the test). After this, we drew a line of best fit up to the person's estimated maximum HR in order to identify the corresponding estimated maximal workrate and estimated VO_{2max} (see Figure 3). A paired t test revealed a

significant difference between measured and predicted VO_{2max} ($p < 0.0001$, see Figure 2) with an average underestimation equal to -12.7 ml·kg⁻¹·min⁻¹ (which is expected since the extrapolation method uses maximal cycle ergometer VO_{2peak} scores as the criterion measure instead of treadmill VO_{2max} scores). Unexpectedly, other studies have reported an overestimation of VO_{2max} (Grant, Joseph, & Campagna, 1999; Zwiren, Freedson, Ward, Wilke, & Rippe, 1991) using the YMCA extrapolation method. However, the utility of these comparisons appear futile since the much more precise multiple regression models should replace these paper and pencil techniques (e.g., extrapolation or nomogram methods) when estimating VO_{2max}.

We also cross validated three existing VO_{2max} multiple linear regression models by using the data we collected (e.g., age, gender, body mass, PFA score, PA-R score, maximal treadmill speed, maximal treadmill grade, cycle workrate, etc.) and inserting the appropriate data into each respective regression model (Bradshaw et al., 2005; George et al., 2000; George et al., 2007. These results (see Table 3) surprisingly show that the existing submaximal cycle ergometer equation (George et al., 2000) did not cross validate well using our data, with estimated VO_{2max} scores overpredicted by 4.87 ml·kg⁻¹·min⁻¹ ($p > 0.0001$) However, the nonexercise model ($p = 0.42$) and maximal GXT model ($p = 0.50$) accurately predicted VO_{2max} scores using our data. It is not possible to identify the exact reasons as to why the George et al. (2000) cycle ergometer equation did not generate acceptable cross validation results using our data, but we can provide some possible hypotheses: First, measured VO_{2max} may not have been accurately recorded in the George et al. (2000) study (due to equipment error) as compared with this study.

Although this is not likely, it is possible since the data in the present study cross validate

well with the other two equations. Second, the cycle ergometer procedures used in the

George et al. (2000) study and in the present study were slightly different in that

workrates were increased using two different approaches (although both studies

employed Monark cycle ergometers). For example, in the George et al. (2000) study the

workrate was adjusted by simply turning the knob on a calibrated Monark cycle

ergometer, while in the present study standard weight plates were added to a basket

hanging directly from the resistance strap circling the flywheel of the cycle ergometer

(thus, replacing the need of calibrating the cycle ergometer since the hanging weights

provided the exact resistance required). Consequently, the cycle ergometers in the

George et al. (2000) study may not have been calibrated correctly or did not reflect an

accurate workload setting during the actual test. Finally, it is possible that participants in

the George et al. (2000) study were dissimilar in some way as compared with the current

study; however, this seems unlikely since the demographics of the two samples are

similar and mean VO_{2max} scores (44.4 ± 6.5 ml·kg^{-1}·min^{-1} vs. 44.9 ± 8.2 ml·kg^{-1}·min^{-1}) are

nearly identical.

We elected to use a pedal rate of 70 rpm as was employed in the George et al.

(2000) study. This pedal rate appears to be realistic for younger, higher-fit participants.

The main advantage of using 70 rpm (instead of 50 rpm) is decreased quadriceps fatigue,

because a faster pedal cadence lowers the inertial resistance, which emphasizes more of a

speed component than a strength component during the exercise. In addition, the test

may be shorter in duration since the participant exercises at a higher workrate and

possibly attains the 70% steady-state HR threshold in less time. Based on our data, 22 participants completed the test at the end of Stage 1, 89 participants at the end of Stage 2, and two participants at the end of Stage 3. The average time to complete the submaximal cycle test equaled 6.26 ± 1.39 min. In terms of perceived exertion, most participants tolerated the submaximal cycle test well and reported reasonable full-body RPE scores (13.6 ± 1.9; which corresponds with a "somewhat hard" intensity) at the end of the cycle test. In addition, we had our participants report RPE scores based on how tired their quadriceps felt at the end of the cycle test and these scores (13.6 ± 2.4) were nearly identical with the full-body RPE scores. However, two female participants reported a full-body RPE score of 18 and 19, and four female participants reported a quadriceps RPE score from 18–20. Thus, in some cases extra attention may be necessary to ensure that participants do not reach excessively high levels of quadriceps muscle exertion during the test. When this becomes a concern, one alternative is to have the participant repeat the test at a lower workrate than what is recommended in Figure 1.

As with all investigations, this study warrants future research to answer additional questions. First, it would be useful to compare Monark cycle ergometer workloads when hanging weights from the cycle's flywheel strap versus using the cycle's built-in system for adjusting workloads, to ensure that both techniques generate identical workload values during the test. Second, additional research should seek to improve and fine-tune the PFA and PA-R variables (and other possible nonexercise variables) in an effort to improve the accuracy of VO_{2max} regression models. Third, future studies should develop an age-generalized regression model (using the submaximal cycle ergometer protocol;

see Figure 1) which includes a broader age range (from 18 to 65 years); allowing younger, higher fit participants to assume a pedal rate of 70 rpm while giving older, lower-fit participants the option of pedaling at a slower pace (e.g., 50–60 rpm). Fourth, additional studies are needed to cross validate the regression model created in this study across a variety of samples (with participants of similar age and CRF fitness levels) to determine if the PRESS statistics generated in this study ($R_{PRESS} = 0.90$, $SEE_{PRESS} = 3.56$ ml·kg^{-1}·min^{-1}) are comparable using actual cross validation data.

In conclusion, this study achieved the goal of developing a relatively accurate ($R = 0.91$, $SEE = 3.36$ ml·kg^{-1}·min^{-1}) VO$_{2max}$ multiple linear regression equation using cycle ergometry. The addition of nonexercise questionnaires increased the precision of VO$_{2max}$ estimates and was an educational tool to help participants understand about their physical activity and exercise intensity levels. The accompanying submaximal cycle ergometer protocol is efficient and only requires moderate exertion levels while eliciting submaximal values in order to predict VO$_{2max}$ in healthy college-aged populations. In addition, the test is quick, cost effective, and poses little threat of injury to healthy participants. Future research to validate the reliability and generalizability of this protocol with a larger spectrum of participants is now warranted.

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Table 1

Descriptive statistics for the total, female, and male participants

Variable	Total (N = 105)	Females (n = 52)	Males (n = 53)
Age (yr)	23.5 ± 2.8	22.4 ± 3.1	24.6 ± 1.87
Height (m)	1.73 ± 0.09	1.66 ± 0.62	1.80 ± 0.07
Body mass (kg)	74.2 ± 15.1	65.27 ± 9.02	83.04 ± 14.70
BMI ($kg \cdot m^{-2}$)	24.6 ± 3.62	23.57 ± 3.02	25.65 ± 3.89
PFA score	15.7 ± 4.3	14.46 ± 4.2	17.0 ± 4.2
PA-R score	4.7 ± 2.1	4.8 ± 2.1	4.6 ± 2.2
Submaximal Cycle Test			
HR (bpm)	164.2 ± 13.0	170.5 ± 10.8	158.0 ± 12.0
Watts (W)	115.3 ± 27.0	124.9 ± 33.1	105.5 ± 13.3
Ending RPE	13.6 ± 1.9	14.3 ± 1.7	12.8 ± 1.8
Maximal Treadmill Test			
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.88 ± 8.24	39.96 ± 5.78	49.7 ± 7.42
HR_{max} ($beats \cdot min^{-1}$)	191.9 ± 8.1	190.0 ± 8.0	193.7 ± 7.8
Maximum RPE	19.5 ± 0.6	19.4 ± 0.6	19.6 ± 0.5
RER ($VCO_2 \div VO_2$)	1.15 ± 0.06	1.16 ± 0.06	1.13 ± 0.05

All data = mean ± SD
PFA = perceived functional ability (2-26 point scale)
PA-R = physical activity rating (10-point scale)

Table 2

Submaximal cycle ergometer regression equation (N = 105)

Variable	β	β-weight
Intercept	54.513	
Gender (0 = female, 1 = male)	9.752	0.594
Body mass (kg)	-0.297	-0.544
Perceived Functional Ability (PFA)	0.739	0.388
Exercise watts	0.077	0.305
Exercise Heart Rate	-0.072	-0.116
R	0.91	
SEE ($ml \cdot kg^{-1} \cdot min^{-1}$)	3.36	
R_{PRESS}	0.90	
SEE_{PRESS} ($ml \cdot kg^{-1} \cdot min^{-1}$)	3.56	

Table 3

Paired t test analyses

	Mean difference (ml·kg^{-1}·min^{-1})	*p* value
Maximal GXT equation (George et al., 1996)	-0.21	0.50
Nonexercise equation (Bradshaw et al., 2005)	+0.36	0.42
Submaximal cycle ergometer equation (George et al., 2000)	+4.87	< 0.0001

Warm-Up
Workload: 1.0 kp, 420 kpm·min^{-1}
Duration: 2 min

	Cycle Protocol Column 1	Cycle Protocol Column 2	Cycle Protocol Column 3
Ending Warm-up HR	If HR is ≥ 60%, stay within this column and move to Stage 1	If HR < 60%, for any female and males < 73.0 kg stay within this column and move to Stage 1	If HR < 60%, for male > 73.1 kg stay within this column and move to Stage 1

Stage 1			
Workload	Increase to 1.0 kp (420 kpm·min^{-1})	Increase to 1.5 kp (630 kpm·min^{-1})	Increase to 2.0 kp (840 kpm·min^{-1})
Duration	1–2 min	3–4 min	3–4 min
If steady-state HR is ≥ 70% of age-predicted maximum HR, then proceed to the cool-down; if steady-state HR is < 70%, then move to Stage 2 (staying within the same column)			

Stage 2			
Workload	Increase to 1.5 kp (630 kpm·min^{-1})	Increase to 2.0 kp (840 kpm·min^{-1})	Increase to 2.5 kp (1050 kpm·min^{-1})
Duration	3–4 min	3–4 min	3–4 min
If steady-state HR is ≥ 70% of age-predicted maximum HR, then proceed to the cool-down; if steady-state HR is < 70%, then move to Stage 3 (staying within the same column)			

Stage 3			
Workload	Increase to 2.0 kp (840 kpm·min^{-1})	Increase to 2.5 kp (1050 kpm·min^{-1})	Increase to 3.0 kp (1260 kpm·min^{-1})
Duration	3–4 min	3–4 min	3–4 min
If steady-state HR is ≥ 70% of age-predicted maximum HR, then proceed to the cool-down; ideally exercise HR should not exceed 85%			

Cool Down
Workload: < 1.0 kp at ≈ 40–50 rpm
Duration: Continue until recovery HR is ≤ 120 bpm

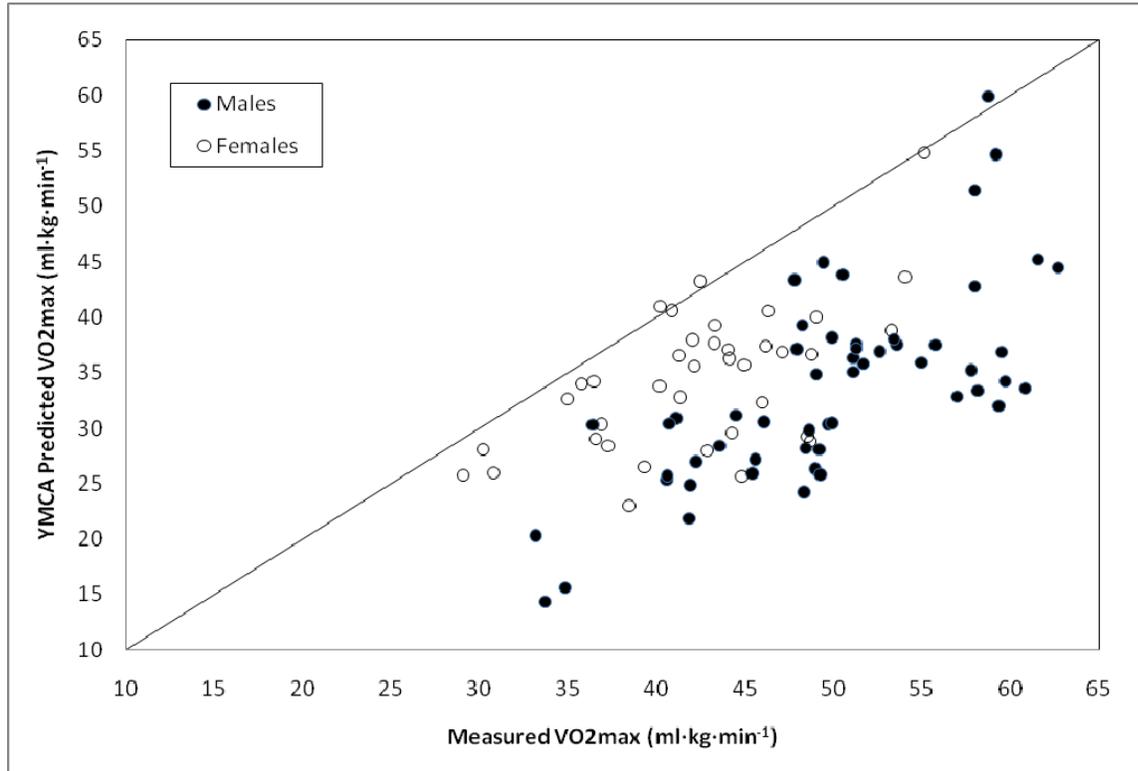Figure 1. Modified BYU submaximal cycle ergometer protocol

Figure 2.   Predicted VO$_{2max}$ vs. Measured VO$_{2max}$ Scatter Plot (based on the regression model generated in the present study; see Table 2).
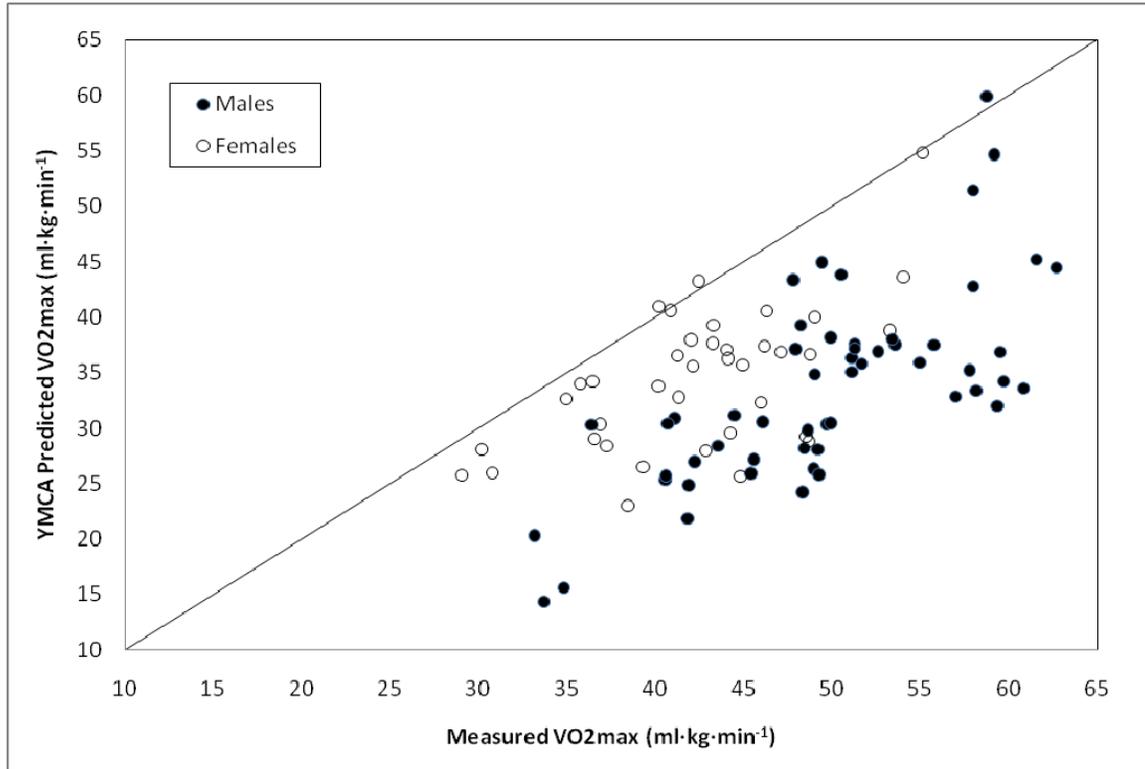
Figure 3. Predicted VO₂ₘₐₓ vs. Measured VO₂ₘₐₓ Scatter Plot (based on cross-validation data using the YMCA extrapolation method)

Appendix A

Prospectus

Chapter 1

Introduction

The criterion measure of cardiorespiratory fitness (CRF) is a person's maximal oxygen uptake (VO_{2max}; Montoye, Ayen, & Washburn, 1986).   Submaximal testing is a popular and effective way of evaluating CRF and is valuable in developing individualized exercise programs, monitoring progress throughout an exercise program, and educating participants about their risk for cardiovascular disease (American College of Sports Medicine (ACSM), 2006; Milani, Lavie, Mehra, & Ventura, 2006). Submaximal tests have certain advantages over maximal tests in that groups of participants can be tested at one time, specialized lab equipment is unnecessary, and test administrators require less training.

Sjostrand (1947) and Astrand and Ryhming (1954) were the first to develop submaximal cycle ergometer protocols.   Since then, researchers have developed many different methods of predicting VO_{2max} from submaximal workloads using a cycle ergometer (ACSM, 2006; Astrand & Ryhming, 1954; George, et al., 2000; Golding, 2000; Leger, et al., 1992; Sjostrand, 1947; Swain & Wright, 1997; Swank, et al., 2001). There are several distinct advantages to using a cycle ergometer rather than other modes of exercise (such as treadmills or stepping benches) when predicting VO_{2max}. For example, 1) cycle ergometry allows for the selection of precise workrates which can be expressed with exact units of power ($kgm \cdot min^{-1}$); 2) cycle ergometers require minimal space and are easy to transport; 3) cycle ergometer exercise is a non-weight-bearing

activity that is usually well tolerated by individuals with orthopedic or other physical limitations; and 4) heart rate (HR), blood pressure, and electrocardiographic data are easily collected during the test protocol. In addition, submaximal cycle ergometer tests provide accurate estimates of CRF in a variety of populations (Fox, 1973; Golding, Meyers, & Sinning, 1989; Kasch, 1984; Siconolfi, Cullinane, Carleton, & Thompson, 1982).

There are also some limitations to submaximal cycle ergometer testing. The first is the incongruity among researchers about the best method of predicting VO_{2max} from a submaximal cycle ergometer test. The Astrand and Ryhming (1954) method uses a nomogram based on gender, power output, and exercise HR. Golding (2000) uses a method where HR responses to submaximal workloads are extrapolated to the age-predicted maximum HR (220-age), from which maximal workload and VO_{2max} can be predicted. In the past, these methods have provided a convenient and accurate system for estimating VO_{2max}, but with the advent of computers and programmable calculators these methods are now antiquated. With today's available technology using a single regression equation to predict VO_{2max} is a more convenient and precise way of estimating VO_{2max} (ACSM, 2006; Arts, Kuipers, Jeukendrup, & Saris, 1993; Ebbeling, Ward, Puleo, Widrick, & Rippe, 1991; George, et al., 2000; Hartung, Blancq, Lally, & Krock, 1995; Jessup, Tolson, & Terry, 1974; Lang, Latin, Berg, & Mellion, 1992; Latin & Berg, 1998; Latin, Berg, Smith, Tolle, & Woodbybrown, 1993; Leger, et al., 1992; Mastropaolo, 1970; Mertens, Kavanagh, & Shephard, 1994; Montoye, et al., 1986; Stanforth, et al.,

1999). Although there are many regression equations available for use, there is an ongoing need to improve the accuracy of these equations.

A second potential limitation of submaximal cycle ergometer testing is that the predictor variable, VO_{2max}, varies with the mode of testing (i.e., cycle ergometry and treadmill testing). In untrained populations, VO_{2max} collected on a cycle ergometer has been found to be 3–29% lower than the VO_{2max} values collected using a treadmill (Bassett & Boulay, 2000; Beasley, Plowman, & Fernhall, 1989; Davies, 1968; Greiwe, Kaminsky, Whaley, & Dwyer, 1995; Hartung, Krock, Crandall, Bisson, & Myhre, 1993; Hermansen & Saltin, 1969; Lockwood, Yoder, & Deuster, 1997; McKay & Banister, 1976; Milani, et al., 2006; Swain & Wright, 1997). However, the general population of the United States does not employ bicycles as a main mode of transportation, which, as shown in the previously cited studies, may lead to underestimates of VO_{2max}. In the current study the college-aged participants will not be trained cyclists, so it is important for treadmill VO_{2max} data to be used instead of cycle ergometer VO_{2max} data as the dependent variable. In the United States a consistent use of the treadmill VO_{2max} value as the criterion or dependent variable should be used, since most people are accustomed to walking or jogging, in order to provide predictive consistency among researchers in exercise physiology labs.

A final concern in cycle ergometry is the pedal rate (rpm) that is traditionally used. To date, most submaximal tests employ a pedal rate of 50 rpm (ACSM, 2006; Astrand & Ryhming, 1954; Golding, 2000). It is speculated that the pedal rate of 50 rpm was adopted to accommodate lower-fit individuals or to simplify calculating power

output. However, the findings of Swain and Wright (1997) indicate that a pedal rate of 50 or 80 rpm is valid for predicting VO_{2max} on a submaximal cycle ergometer (Astrand & Rodahl, 1977; Banister & Jackson, 1967; Coast, Cox, & Welch, 1986; Garry & Wishart, 1931; Hagberg, Giese, & Schneider, 1978; Hermansen & Saltin, 1969; McKay & Banister, 1976; Pivarnik, Montain, Graves, & Pollock, 1988). Although slower pedal rates may be more favorable for older, unfit individuals, a faster pedal cadence can reduce pain and fatigue of the quadriceps muscles when working at higher workloads. This is because decreasing the resistance and force and increasing the pedal cadence can produce the same power output as a lower pedal cadence with more resistance, which will reduce stress on the quadriceps.

Recently, George et al. (2000), developed a submaximal cycle ergometer protocol that overcomes some of the concerns of traditional submaximal cycle ergometry. For example, the prediction equation was developed using treadmill VO_{2max}, along with a power output using a pedal cadence of 70 rpm. The accuracy of this prediction model was acceptable ($R = .88$, $SEE = 3.12$ ml$\cdot$kg$^{-1}\cdot$min^{-1}) and participants appeared to respond well to the overall testing experience.

In addition to the many submaximal exercise methods and equations developed to predict VO_{2max}, there have been nonexercise prediction models developed to predict VO_{2max}. The nonexercise methods use questions with varying ranges of responses in conjunction with the gender, age, height, and weight. In this study, two nonexercise questionnaires will be used to aid in the prediction of VO_{2max} from the equation developed from the submaximal cycle ergometer protocol. The first is the Physical

Activity Rating (PA-R; Jackson, et al., 1990) and the second is the Perceived Functional

Ability (PFA; George, Stone, & Burkett, 1997) questionnaires. The PA-R questionnaire

has participants answer questions regarding their physical activity during the last six

months and has an R value of 0.81 and a standard error of the estimate (SEE) of 5.35 ml ·

$kg^{-1} \cdot min^{-1}$. The PFA questions ask about the pace at which an individual could run one

and three miles without becoming overly breathless or fatigued, and it has an R value of

0.85 and a SEE of 3.44 ml · $kg^{-1} \cdot min^{-1}$.

The purpose of this study is to attempt to enhance the equation developed by

George et al. (2000) by including additional predictor variables that were not included in

their regression model for predicting VO_{2max} in college-aged subjects using a submaximal

cycle ergometer protocol. The additional predictor variables will include questions

regarding participants perceived functional ability (George, et al., 1997) and physical

activity rating (Jackson, et al., 1990). In addition, a minor modification of the

submaximal cycle ergometer protocol developed by George et al. (2000) will be

evaluated.

Statement of Purpose

The purpose of this study is to enhance the submaximal cycle ergometer protocol

and regression model developed by George el al. (2000) to accurately predict VO_{2max}.

Hypotheses

Hypothesis: The submaximal cycle ergometer test is a valid protocol and the

regression model accurately predicts VO_{2max}.

Null Hypothesis: The submaximal cycle ergometer test is not a valid protocol and the regression model does not accurately predict VO_{2max}.

Assumptions

1. Participants will be able to successfully perform the submaximal cycle ergometer test and the maximal treadmill graded exercise test (GXT).

2. Participants will follow pretesting instructions and procedures (e.g., refrain from vigorous exercise the day of the test; abstain from consuming food, alcohol, caffeine, or using tobacco products 3 hours prior to testing; and drink ample fluids).

3. Participants will not be trained cyclists.

4. Participants will self-select a treadmill speed/exercise intensity that corresponds to their current fitness level.

5. All equipment will be calibrated correctly.

6. Participants will achieve their actual VO_{2max}.

Delimitations

1. Participants will be 19–29-year-old male and female college-aged volunteers.

2. Participants will be healthy.

3. Participants must be able to complete the submaximal cycle ergometer test and the maximal GXT on a treadmill.

4. Participants will be recruited from the Brigham Young University campus, a primarily Caucasian population (85%).

Limitations

The prediction equation generated in this study will be applicable for use only with college-aged adults 19–29 years old with physical characteristics similar to the study group.

Definition of Terms

Cardiorespiratory Fitness—Ability of the circulatory and respiratory systems to adequately provide nutrients and oxygen to the cells of the body in order to sustain moderate to high intensity exercise for extended amounts of time.

Age Predicted Maximum Heart Rate—Estimate of maximum heart rate by subtracting ones age from 220.

Steady State Heart Rate—A homeostatic state of heart rate during a constant intensity of exercise.

VO_{2max}—Maximum amount of oxygen transported and utilized by the body per minute, expressed as either: $ml·min^{-1}$ or $ml·kg^{-1}·min^{-1}$.

Respiratory Exchange Ratio—Volume of carbon dioxide produced divided by the volume of oxygen consumed (VCO_2 L/min)/(VO_2 L/min).

Chapter 2

Review of Literature

Physical inactivity is one of the leading modifiable risk factors for coronary heart disease and other cardiovascular diseases (Blair, et al., 1989) and small improvements in fitness may cause a decrease in mortality (ACSM, 2006; Blair, et al., 1989; Erikssen, et al., 1998; Vanhees, et al., 2005). Myers et al. (2002) showed that exercise capacity is a strong predictor of the risk of death in healthy and diseased individuals. Thus, measuring and stratifying cardiorespiratory fitness (CRF) levels provides important fitness and health information. The criterion measure of CRF is maximal oxygen uptake (VO_{2max}), which is the maximal amount of oxygen the body utilizes during strenuous exercise. VO_{2max} is measured during a maximal graded exercise test (GXT). This manner of testing requires highly trained individuals, expensive equipment, and, in many situations, a physician to oversee the test in case of a medical emergency. Submaximal exercise tests have been developed to predict VO_{2max} based on responses to various modes of exercise. Submaximal testing is less strenuous, less expensive, requires less equipment, and can often be administered to groups of individuals.

Submaximal Cycle Ergometry

Submaximal cycle ergometry is an excellent tool for estimating VO_{2max} (ACSM, 2006). Since the early twentieth century many submaximal cycle ergometer protocols have been developed. Sjostrand (1947) and Astrand and Ryhming (1954) developed submaximal cycle ergometer tests to estimate VO_{2max} based on the linear relationship between HR and oxygen uptake. The HR/VO_2 relationship is the premise for the various

submaximal cycle ergometer protocols and prediction equations that have since been developed (ACSM, 2006; Fox, 1973; George, et al., 2000; Golding, 2000; Greiwe, et al., 1995; Hagberg, Mullin, Giese, & Spitznagel, 1981; Hartung, et al., 1995; Mastropaolo, 1970; Siconolfi, et al., 1982).

George et al. (2000) developed a submaximal cycle ergometer protocol using 172 males and females, from 18–39 years of age. All individuals began pedaling at 70 rpm and the workload for each subsequent stage was determined by the individual's gender, weight, and HR response to the warm-up workload. Each individual completed a maximal GXT on a treadmill to measure VO_{2max}. A regression equation was developed to estimate VO_{2max} from the predictor variables of gender, age, weight (kg), power output (watts), and HR ($R = .88$, *SEE* = 3.12 ml·kg^{-1}·min^{-1}).

Methods of Predicting VO_{2max} from Submaximal Cycle Ergometry

Submaximal cycle ergometry is a popular mode of testing, but there are some limitations regarding methods and protocols. Submaximal cycle ergometry was developed before computers and programmable calculators, and the main methods of predicting VO_{2max} from submaximal workloads on a cycle ergometer were dependent upon nomograms or extrapolating data points on graphs, all of which were performed by hand (Astrand & Rhyming, 1954; Golding, 2000). Astrand and Ryhming (1954) developed a nomogram based on gender, power output, and exercise HR. Golding (2000) reported a method where HR and workload from different workrates were plotted by hand on graph paper. A line is then drawn through data points representing submaximal HRs and extended to the age-predicted maximum HR. From this intersection a line is

drawn straight down to where maximum workload is estimated. From the maximum workload, estimated VO_{2max} value can be calculated or derived from standard conversion tables. Traditional methods, as opposed to using prediction equations, for predicting VO_{2max} from submaximal tests has become cumbersome because of the availability of computers and programmable calculators and inversely makes the use of prediction equations more common. In order to rate individual submaximal prediction equations, Kline et al. (1987) developed a method consisting of four criteria: 1) accuracy and validity of the prediction, 2) ease of administering the test protocol, 3) the level of risk the participant is exposed to, and 4) applicability of the equation to large populations.

Maximal Treadmill vs. Maximal Cycle Ergometer VO_2 Values

Another possible limitation is found within the prediction equations, where the VO_{2max} value is used as the dependent variable in the developed prediction equation. Some researchers use maximal cycle ergometer VO_{2max} values (Arts, et al., 1993; Fox, 1973; Greiwe, et al., 1995; Hagberg, et al., 1981; Lang, et al., 1992; Latin, et al., 1993; Malek, Berger, Housh, Coburn, & Beck, 2004; Siconolfi, et al., 1982; Stanforth, et al., 1999; Storer, Davis, & Caiozzo, 1990; Swain & Wright, 1997; Wilmore, et al., 1986), while others use VO_{2max} values from a treadmill as the dependent variable (Beekley, et al., 2004; George, et al., 2000; Grant, Corbett, Amjad, Wilson, & Aitchison, 1995; Hartung, et al., 1993; Lockwood, et al., 1997; Reneau, Pujol, Moran, Bergman, & Barnes, 2001). A maximal VO_2 test on a cycle ergometer elicits a VO_{2peak} instead of a VO_{2max} because it is non-weight-bearing, causing oxygen utilization to usually be lower than weight-bearing exercises, such as on a treadmill. However, the general population of the

U.S. does not employ bicycles as a main mode of transportation and research has shown that in untrained populations, VO_{2max} values obtained from a cycle ergometer were 3%-29% lower than VO_{2max} values obtained via treadmill tests (Bassett & Boulay, 2000; Beasley, et al., 1989; Davies, 1968; Greiwe, et al., 1995; Hartung, et al., 1993; Hermansen & Saltin, 1969; Lockwood, et al., 1997; McKay & Banister, 1976; Milani, et al., 2006; Swain & Wright, 1997). Therefore, using VO_{2max} values from a cycle ergometer would cause under-predictions from submaximal equations for populations unfamiliar with cycling. Prediction equations used in the U.S., for submaximal cycle ergometer testing should use treadmill VO_{2max} values because most U.S. citizens are accustomed to walking or jogging rather than cycling.

Pedal Rates of Cycle Ergometer Protocols

Pedal rates (rpm) differ among protocols when assessing both maximal and submaximal VO_{2max}. To date, many submaximal tests use a pedal cadence of 50 rpm (Astrand & Rhyming, 1954; Golding, 2000; Greiwe, et al., 1995; Hartung, et al., 1995; Mastropaolo, 1970; Siconolfi, et al., 1982)**.** It is speculated that 50 rpm was chosen as the pedal cadence for early tests in order to suit the needs of less fit individuals and to make power output calculations easier. Although 50 rpm has been used frequently, Swain and Wright (1997) found that 50 or 80 rpm are valid for predicting VO_{2max} on a submaximal cycle ergometer. Swain and Wright (1997) concluded that either cadence can be used depending on the preference of the participant. Other researchers have found pedal rates of 80–120 rpm tend to elicit the greatest VO_{2max} values in individuals unfamiliar with cycling (Astrand & Rodahl, 1977; Banister & Jackson, 1967; Coast, et

al., 1986; Garry & Wishart, 1931; Hagberg, et al., 1978; Hermansen & Saltin, 1969; McKay & Banister, 1976; Pivarnik, et al., 1988). Although slower pedal rates are favorable for unfit individuals, a faster pedal cadence may reduce quadriceps muscle pain and fatigue in this population (Banister & Jackson, 1967; McKay & Banister, 1976)**.** Another advantage of using a higher pedal cadence is that less resistance can be used to produce the same workloads as a lower pedal cadence with more resistance (McKay & Banister, 1976) which can reduce stress on the quadriceps.

The prediction equation and the submaximal cycle ergometer protocol developed by George et al. (2000) fulfill three of the four criterion set forth by Kline et al. (1987) for acceptable prediction equations. The protocol is easy to administer and has a low level of risk for participants and the equation gives valid and accurate estimates of VO_{2max}. The only criterion it does not fulfill is the applicability of the equation to large populations, and this is because participants aged 19–39 were used to develop both the equation and the protocol.

In order to enhance the equation developed by George et al. (2000), two additional predictor variables will be included. The additional predictor variables will include two questions regarding participants perceived functional ability to cover a 1-mile and a 3-mile distance (George, et al., 1997) and one question where they report physical activity habits during the past six months (Jackson, et al., 1990).

Chapter 3

Methods

Participants, Procedures, and Data Collection

One hundred healthy college-aged participants, 50 male and 50 female 19–29 years of age, will be recruited from the Brigham Young University (BYU) campus. Testing will include a modified BYU submaximal cycle ergometer protocol (George, et al., 2000) and a maximal treadmill GXT (George, 1996). Prior to testing, participants will be asked to drink ample fluids and refrain from vigorous exercise the day of the test. They will also be asked to abstain from consuming food, alcohol, caffeine, or using tobacco products three hours prior to testing (ACSM, 2006). Each subject will be fitted with a HR monitor (POLAR, Lake Success, NY) to measure HR during the modified BYU submaximal cycle ergometer protocol and the maximal GXT. Preceding testing, each participant will be informed of the protocols, nature, and risk of the study and give written informed consent. Additionally, each participant will complete a Physical Activity Readiness Questionnaire (PAR-Q) prior to participation. Age, gender, weight, and height will be recorded, and the Borg (1982) 15-point rate of perceived exertion (RPE) scale will be explained. Weight and height will be measured while wearing light exercise clothing, without shoes. Participants will also respond to three questions regarding their perceived functional ability (PFA; George et al., 1997) and perceived physical activity rating (PA-R; Jackson, et al., 1990).

Modified BYU submaximal cycle ergometer protocol. Prior to the modified BYU submaximal cycle ergometer protocol (George, et al., 2000), seat height of the cycle

ergometer (Ergomedic 894E, Monark, Sweden) will be adjusted to accommodate an approximate five degree angle with the leg in the extended position. Participants will be instructed to maintain a pedal cadence of 70 rpm throughout the test by pedaling in time with an electronic metronome and visual display on the cycle ergometer. The modified BYU submaximal cycle ergometer protocol (see Figure 1) begins with a 2 minute Warm-up Stage at a workload of 1.0 kp. Heart rate will be measured at the end of the warm-up stage and again during the last 10 seconds of the last two minutes of each subsequent stage to ensure a steady-state HR. Steady-state HR will be defined as two consecutive HR measurements within ± 5 bpm (ACSM, 2006). If HR is not in steady state, the stage will be extended 1 additional minute. After the 2 minute Warm-up Stage, if HR is between 120–175 bpm, stage one will begin and continue at a workload of 1.0 kp for 1 to 2 minutes. After the Warm-up Stage, if HR is below 120 bpm for all females and males weighing less than 73.0 kg, the workload will increase to 1.5 kp during Stage 1. For males over 73.0 kg who have a HR less than 120 bpm at the end of the warm-up phase, the workload will increase to 2.0 kp during Stage 1. For all participants, the Stage 2 workload will increase by 0.5 kp from the Stage 1 workload. The exercise test will be terminated when a steady-state HR is reached in Stage 2 after 3 to 4 minutes at which time subjects will be asked to rate their overall exertion and the exertion of their quadriceps on the Borg RPE scale. Subjects will be allowed to cool down at a self-selected workload and pedal rate until HR is less than 120 bpm. Participants will reach at least 70% of their age-predicted maximum HR during the final stage of the submaximal test.
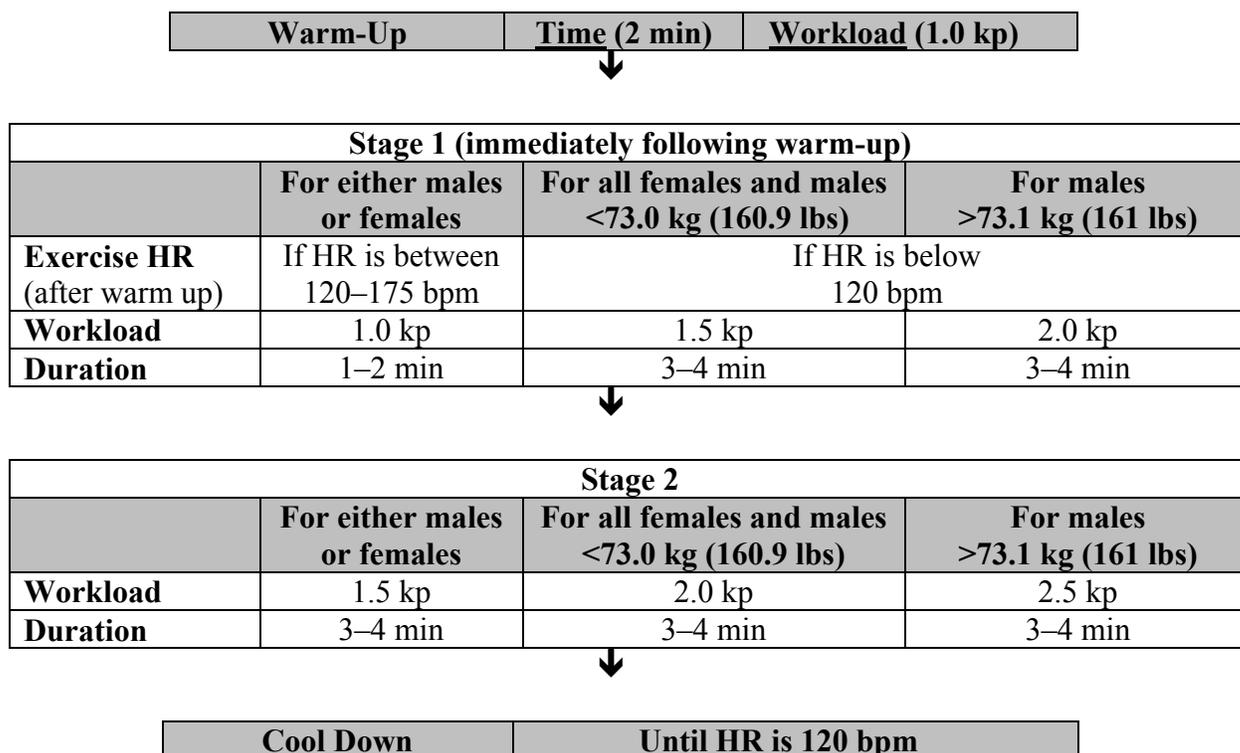
Warm-Up	Time (2 min)	Workload (1.0 kp)

⬇

Stage 1 (immediately following warm-up)			
	For either males or females	**For all females and males <73.0 kg (160.9 lbs)**	**For males >73.1 kg (161 lbs)**
Exercise HR (after warm up)	If HR is between 120–175 bpm	If HR is below 120 bpm	
Workload	1.0 kp	1.5 kp	2.0 kp
Duration	1–2 min	3–4 min	3–4 min

⬇

Stage 2			
	For either males or females	**For all females and males <73.0 kg (160.9 lbs)**	**For males >73.1 kg (161 lbs)**
Workload	1.5 kp	2.0 kp	2.5 kp
Duration	3–4 min	3–4 min	3–4 min

⬇

Cool Down	Until HR is 120 bpm

Figure 1: Modified BYU Submaximal Cycle Ergometer Protocol

ASU maximal graded exercise test protocol. After completion of the modified

BYU submaximal cycle ergometer protocol, subjects will rest for 10–15 minutes during

which time the Arizona State University (ASU) maximal GXT protocol (George, 1996)

will be explained. During the maximal GXT, VO_2 will be measured using a metabolic

cart (ParvoMedics TrueOne 2400, Sandy, UT). Prior to testing, the flow meter will be

calibrated using a three liter syringe at five different flow rates. The oxygen and carbon

dioxide analyzers will be calibrated using room air and medical grade gasses of known

concentrations. Information about VO_2 and respiratory exchange ratio (RER) will be

gathered continuously, averaged, and printed every 15 seconds. Stage 1 of the maximal

GXT requires the participant to walk on the treadmill (Track Master, Full Vision, Inc.,

USA) for 1 minute at a self-selected walking pace. This is followed by walking, jogging

or running at a comfortable self-selected pace that could be conceivably maintained for

20 to 30 minutes. After maintaining the self-selected pace for 1 minute, the grade of the

treadmill will increase to 1.5% and increase an additional 1.5% each following minute

until participants reach volitional fatigue and are unable to continue the test despite

verbal encouragement. The self-selected treadmill speed and the final treadmill grade

(%), sustained for a full minute before exhaustion, will be recorded along with maximum

RPE and HR. Upon voluntary completion of the test, participants will cool down by

walking on the treadmill at a self-selected pace for 5 to 10 minutes.

After the maximal GXT, maximum RER, and VO_{2max} values will be recorded.

The four highest 15-second interval scores near the end of the GXT will be averaged to

determine VO_{2max}. In order to be considered a valid VO_{2max}, at least two of the following

three criteria need to be met:

1. Maximum HR within 15 beats of age-predicted maximal heart rate (220-age).

2. RER equal to or greater than 1.10.

3. No increase in VO_2 with increasing workloads (ACSM, 2006).

Statistics

All data will be analyzed using SAS statistical software (SAS 9.1, SAS Institute,

Inc., Cary, NC) with a level of significance set at $p < 0.05$. Stepwise regression will be

used to determine the statistical strength and contribution of possible independent

variables (e.g., age, gender, body mass, height, body mass index (BMI), race, exercise

HR, exercise work rate, the PFA questions [equaling the sum of the two questions, 2–26],

and the PA-R question) in the prediction of VO_{2max}. A multiple linear regression equation will be generated using those independent variables that provide the most accurate VO_{2max} prediction. To assess the predictive accuracy of the regression equation, correlation coefficients (R-values) and standard error of estimates (SEE) will be computed. To account for possible shrinkage when using the prediction equation on independent but similar samples, predicted residual sums of squares (PRESS) statistics will also be calculated (Holiday, Ballard, and McKeown, 1995).

Three paired t-test analyses will be employed to cross validate three existing VO_{2max} prediction equations using the data collected in the current study. These multiple linear regression equations will include the George et al., 2000 submaximal cycle ergometer equation, the George et al., 1996 GXT equation, the Bradshaw et al., 2005 nonexercise prediction equation.

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Appendix A-1

Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people, physical activity should not pose any problems or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the carefully and check **YES** or **NO** opposite the question if it applies to you. If yes, please explain.

YES **NO**

____ ____   1.   Has your doctor ever said you have heart trouble?
                         Yes, _____

____ ____   2.   Do you frequently have pains in your heart and chest?
                         Yes, _____

____ ____   3.   Do you often feel faint or have spells of unconsciousness or of severe dizziness?
                         Yes, _____

____ ____   4.   Has a doctor ever said your blood pressure was too high?
                         Yes, _____

____ ____   5.   Has a doctor ever said your blood pressure was too low?
                         Yes, _____

____ ____   6.   Do you have Diabetes Mellitus or any other metabolic disease?
                         Yes, _____

____ ____   7.   Has your doctor ever said that you have raised cholesterol (serum level above 6.2mmol/L)?
                         Yes, _____

____ ____   8.   Are you, or is there any possibility that you might be pregnant?
                         Yes, _____

____ ____   9.   Do you currently smoke or drink alcohol?
                         Yes, _____

____ ____   10. Is there any history of Coronary Heart Disease in your family?
                         Yes, _____

____ ____   11. Has your doctor ever told you that you have a bone or joint problem(s), such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
                         Yes, _____

____ ____   12. Is there a good physical reason, not mentioned here, why you should not follow an activity program even if you wanted to?
                         Yes, _____

____ ____   13. Do you suffer from any problems of the lower back, i.e., chronic pain, or numbness?
                         Yes, _____

____ ____   14. Are you currently taking any medications? If YES, please specify.
                         Yes, _____

____ ____   15. Do you currently have a disability or a communicable disease? If YES, Please specify,
                         Yes, _____

If you answered NO to all questions above, it gives a general indication that you may participate in physical and aerobic fitness activities and/or fitness evaluation testing. The fact that you answered NO to the above questions, is no guarantee that you will have a normal response to exercise. If you answered Yes to any of the above questions, then you may need written permission from a physician before participating in physical and aerobic fitness activities and/or fitness evaluation testing at the Brigham Young University Human Performance Lab.

_____   _____   _____
        Print Name   Signature   Date

Appendix A-2

Consent to be a Research Subject

Consent to be a Research Subject

Title: Development of a Submaximal Cycle Ergometer Test and Equation to Predict
VO_{2max} in college-aged populations

Introduction. This research study is being conducted by David Nielson, a graduate
student at Brigham Young University, under the direction of James George, Ph.D. The
purpose of this study is to further develop the prediction of cardiorespiratory fitness
(VO_{2max}) using a submaximal exercise test on a stationary bike. You were asked to
participate in this study because you are 19 to 29 years of age.

Procedures. If you consent to participate in this study, you will be asked to:
(a)   Complete the preparticipation questionnaire, which will screen for conditions that
      may result in the ability to safely participate in this study.
(b)   Complete a Physical Activity Rating and Perceived Functional Ability
      questionnaires which asks three questions about your current level of physical
      activity.
(c)   Complete a submaximal bicycle exercise test. During this test you will wear a heart
      rate monitor. This test will begin by pedaling at a light workload for two minutes.
      The workload will then be increased depending on your heart rate response. The
      test will be terminated after completing two more three to four-minute stages of
      exercise at low to moderate intensities. The workload will be adjusted each time
      based on your heart rate response. You will have an active and resting cool-down
      after this test. The total time required to complete this test is less than 15 minutes.
(d)   Complete a maximal graded exercise test on a treadmill. This test will begin after a
      15-20-minute rest from the bike test. During this test you will wear a heart rate
      monitor. You will also wear a nose-clip and breathe through a one-way valve that
      will allow us to measure oxygen consumption. This test will begin by walking at a
      brisk walking pace. You will then select a walking, jogging, or running pace that
      you could conceivably maintain comfortably for 20 to 30 minutes. After the first
      two minutes of this test the incline of the treadmill will increase 1.5% every minute
      until you reach the point of exhaustion and feel you cannot exercise anymore,
      following which you will have an active cool-down. This test should last no longer
      than 15 minutes.

Risks/Discomforts. There are minimal risks associated with participation in this study.
According to the American College of Sports Medicine, the risk of sudden death during a
maximal graded exercise test in a varied population is 1:20,000. Fatalities are generally
associated with underlying disease. The risk for a population of young apparently
healthy college-aged adults is less. The risk of musculoskeletal injuries during exercise
testing is less than that incurred during recreational activities. The risk associated with a
maximal treadmill test is also minimized by screening for common pre-existing
conditions that would warrant exclusion due to presence of known diseases or
characteristics that may result in exercise intolerance. This test will be administered by an

experienced and trained technician. If at any time you feel you need to stop exercising, make this known to the test administrator.

Benefits. At your request, information pertaining to your cardiorespiratory fitness levels (VO_{2max}) will be explained to you. Your exercise test results will be compared to age and gender specific population norms. The results of this study may impact the manner in which cardiorespiratory fitness is assessed in physical education classes, school athletic programs, university exercise physiology labs, and community fitness programs.

Confidentiality. All information provided will remain confidential and will only be reported as group data with no identifying information. All data, including questionnaires will be kept in a locked file cabinet and only those directly involved with the research will have access to them.

Compensation. You will receive a gift card, valued at $10, for completing all of the procedures in this study. No partial compensation will be given if you do not complete the study.

Participation. Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade or standing with the university. You may be excluded or terminated from participating in this study due to pre-existing conditions, scheduling conflicts, or lack of adherence to the procedures.

Questions about the Research. If you have questions regarding this study, you may contact James George, PhD, at 801-422-8778, jim@byu.edu or David Nielson, at 801-422-2679, nie03013@gmail.com.

Questions about your Rights as Research Participants. If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair, 801-422-6461, 133 TLRB, Brigham Young University, Provo, UT 84602, Christopher_Dromey@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (please print): _____

Signature:_____Date:_____

Appendix A-3

Perceived Functional Ability 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). Nonexercise VO_{2max} estimation for physically active college students. *Medicine and Science in Sports and Exercise*, *29(3),* 415–423.

Appendix A-4

Physical Activity Rating Questionnaire

Physical Activity Rating (PA-R) Questionnaire

Select the number that best describes your overall level of physical activity for the previous six MONTHS:

0 = avoid walking or exertion; e.g., always use elevator, drive when possible instead of walking

1 = **light activity:** walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration

2 = **moderate activity:** 10 to 60 minutes per week of moderate activity; such as golf, horseback riding, calisthenics, table tennis, bowling, weight lifting, yard work, cleaning house, walking for exercise

3 = **moderate activity:** over 1 hour per week of moderate activity as described above

4 = **vigorous activity:** run less than 1 mile per week or spend less than 30 minutes per week in comparable activity such as running or jogging, lap swimming, cycling, rowing, aerobics, skipping rope, running in place, or engaging in vigorous aerobic-type activity such as soccer, basketball, tennis, racquetball, or handball

5 = **vigorous activity:** run 1 mile to less than 5 miles per week or spend 30 minutes to less than 60 minutes per week in comparable physical activity as described above

6 = **vigorous activity:** run 5 miles to less than 10 miles per week or spend 1 hour to less than 3 hours per week in comparable physical activity as described above

7 = **vigorous activity:** run 10 miles to less than 15 miles per week or spend 3 hours to less than 6 hours per week in comparable physical activity as described above

8 = **vigorous activity:** run 15 miles to less than 20 miles per week or spend 6 hours to less than 7 hours per week in comparable physical activity as described above

9 = **vigorous activity:** run 20 to 25 miles per week or spend 7 to 8 hours per week in comparable physical activity as described above

10 = **vigorous activity:** run over 25 miles per week or spend over 8 hours per week in comparable physical activity as described above

Source: Modified from Jackson et al., (1990). Prediction of functional aerobic capacity without exercise testing. *Medicine and Science in Sports and Exercise, 22*(6), 863-870.