Creation of a Modified Equation to Predict VO_2 on a Cycle Ergometer

A thesis presented to

the faculty of

the College of Health Sciences and Professions of Ohio University

In partial fulfillment

of the requirements for the degree

Master of Science

Anna R. Gray

June 2012

This thesis titled

Creation of a Modified Equation to Predict VO_2 on a Cycle Ergometer

by

ANNA R. GRAY

has been approved for

the School of Applied Health Sciences and Wellness

and the College of Health Sciences and Professions by

Michael R. Kushnick

Associate Professor of Exercise Physiology

Randy Leite

Dean, College of Health Sciences and Professions

ABSTRACT

GRAY, ANNA R., M.S., June 2012, Physiology of Exercise, Research

Creation of a Modified Equation to Predict VO_2 on a Cycle Ergometer

Director of Thesis: Michael R. Kushnick

INTRODUCTION: Prediction equations are inexpensive, easy and commonly used to estimate the oxygen consumption (VO_2) and caloric expenditure of physical activity, but some of these equations have limitations, including a stated limit of accuracy of the cycling equation up to a work rate (WR) of 200 watts. This is not favorable to trained individuals who can cycle at WR much higher than 200 watts. PURPOSE: To create a VO_2 prediction equation for cycling WR below and above 200 watts. METHODS: Twenty nine participants qualified for this study by achieving a maximal WR (WRmax) of at least 300 watts during a maximal graded exercise test (GXT). These individuals then completed two submaximal exercise trials (SXT). During the SXT, steady state VO_2 was collected for each WR and was analyzed by linear regression. RESULTS: The 29 participants were 20-54 years old, 1.80 ± 0.00 meters tall, weighing 78.29 ± 0.44 kg with a body fat of 9.14 ± 0.21% and a WRmax of 361.13 ± 2.06 watts. According to the analysis of this sample, the data suggests VO_2 (ml/kg/min) = {10.941ml/kg/min x (WR (watts) / body weight (kg))} + 4.522 (ml/kg/min) with an R^2 of 0.96. CONCLUSION: The regression equation created from this data to predict VO_2 is useful to estimate the oxygen consumption and caloric expenditure of trained individuals who cycle below and above 200 watts.

Approved: ____

Michael R. Kushnick

Associate Professor of Exercise Physiology

ACKNOWLEDGMENTS

I greatly appreciate the guidance of my thesis advisors Mr. Michael Clevidence and Dr. Michael Kushnick for developing this research idea and directing me through the thesis process. I would also like to thank Drs. Gordon Brooks, Roger Gilders and Cheryl Howe for serving on my thesis committee and working with me individually throughout this process.

I want to recognize the dependability of the three Exercise Physiology undergraduate students, Julie Brown, Sarah Coccia and Joey Meyer who helped me with data collection and analysis. I also appreciate the dependability of the cyclists of Athens county Ohio who were very willing to come into the lab and participate in this research. I want to thank the Exercise Physiology graduate students of the 2011 and 2012 classes, specifically, Marc Barr, Christa Cocumelli, Travis Fullerton, Ryan Kaya and Brett Winner. They supported me and were always willing to help me with data collection or proof reading my documents.

I would like to express my gratitude to my family, my Dad for proof reading some of my documents and constantly asking me questions pertaining to my research, and my Mom for not talking about my research when I just needed a break. I appreciate my brother Jacob, for being a great role model and for being super critical of my work at times but always encouraging. Finally, I would like to thank Matt Brooks for understanding when I needed to work but also for getting me away from my work and taking me outside or to different cities to watch baseball when I obviously needed a break to relax.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Introduction

Exercise scientists benefit from the equations that have been developed to predict oxygen consumption (VO_2) during exercise. These equations estimate the intensity and caloric expenditure of the activity, while avoiding unnecessary patient discomfort, time consuming procedures, and large laboratory expenses encountered by directly measuring VO_2. The American College of Sports Medicine (ACSM) presents VO_2 prediction equations for five different modes of exercise, four of which have been adjusted over time (ACSM, 1975, 1980, 1986; ACSM, Thompson, Gordon, & Pescatello, 2010; Swain, 2000). Specifically, the VO_2 prediction equation for the cycle ergometer published in the most current ACSM's *Guidelines for Exercise Testing and Prescription* (2010) has been modified twice, in an attempt to improve its accuracy, since it appeared in the first edition (ACSM, 1975) of this publication (Swain, 2000). However, the ACSM suggests a limitation to the use of the cycling equation by stating that it is most suited for work rates (WR) between 300 and 1,200 kilogram (kg) x meter (m) / minute (min) (50 to 200 watts) and loses its accuracy at WR above 1,200 kgm/min (200 watts) (ACSM et al., 2010).

The first change to the cycling equation, presented in the third edition of the ACSM's Guidelines (ACSM, 1986), was the addition of a component that would make the resting portion of VO_2 relative to body weight (BW). The second modification which resulted in the most recent equation is a combination of three different VO_2 prediction equations. These equations were combined in response to research that determined the existing equation, published in the fourth edition of the ACSM Guidelines consistently underestimated VO_2 (ACSM, 1991; Lang, Latin, Berg, & Mellion, 1992; Latin & Berg, 1994; Londeree, Moffitt-Gerstenberger, Padfield, & Lottmann, 1997; Swain, 2000). The current ACSM equation, which first appeared in the sixth edition of the ACSM Guidelines, converts WR to a relative form by dividing it by BW, while including the VO_2 of rest and unloaded cycling as constant values (ACSM et al., 2010).

While athletes today are striving to increase their performance, many experienced cyclists and aerobically trained individuals can cycle at submaximal WR well above 200 watts. Considering this, an equation needed to be developed that can predict VO_2 from WR beyond the 200 watt confine of the ACSM equation.

Significance of Study

A VO_2 prediction equation that is designed to be used both below and above 200 watts will allow for athletic individuals to be able to accurately predict their VO_2 at the rates at which they commonly work.

Purpose

The purpose of this study is to create an equation to predict VO_2 at WR both below and above 200 watts using values from cycle ergometer submaximal exercise trials.

Hypothesis

Using measured VO_2 and WR values from submaximal exercise, an equation will be created with a high coefficient of variation (R^2), to predict VO_2 at WR both below and above 200 watts.

Definition of Terms

*Age predicted heart rate max (HRmax).*The estimated highest heart rate an individual can reach based on their age, calculated as 207-(0.7 x age in years).

Aerobically trained individuals. Those who participate in exercise that requires an increase in oxygen uptake, at least 3 days per week.

American College of Sports Medicine (ACSM). Group of scientists and allied health professionals who work to promote healthy lifestyles in order to help the public lead longer more productive lives.

Maximal graded exercise test (GXT). Multiple stage test with incremental work rates that is designed to measure a participant's physiological responses to maximal exercise.

Maximal oxygen consumption (VO_2max). Greatest rate at which oxygen can be consumed as measured during a GXT.

Maximal work rate (WRmax.) Highest WR achieved during the GXT, calculated from WR and time accomplished during a GXT.

Oxygen consumption (VO_2). Rate of oxygen being used by body tissues.

Steady state oxygen consumption. A leveling off of VO_2 to a difference in oxygen consumption between 30 second measurements of equal to or less than 50 milliliters (ml) or 0.05 liters (L) per minute (min) between 3 and 5 minutes of the stage, or a change equal to or less than 100 ml/min or 0.1 L/min between 5 and 7 minutes of the stage.

Submaximal exercise trial (SXT). Multiple stage exercise test designed to measure a participant's physiological responses while working at less than maximal intensities.

Work rate (WR). A measurement of power, or the rate of work being done. Calculated as the work being accomplished per unit of time, typically reported in watts or kgm/min.

Assumptions

Participants adhered to test administrator's instructions to arrive for all tests fasted for 4 hours and refrained from alcohol, caffeine, nutritional supplements, nicotine, exercise and physical activity above their typical daily routine for 12 hours. Also the assumption was made that each participant worked to failure, to their maximum exertion level during the maximal graded exercise test (GXT).

Limitations

Inclusion criteria of "participating in aerobic exercise at least 3 days per week" and "being familiar with cycle exercise" are subjective. This may have resulted in some individuals not volunteering for the study because they may not have considered themselves familiar, even though they may have been able to reach 300 watts.

The qualifying WR of 300 watts may have been too high for aerobically trained females.

Delimitations

The inclusion criteria of this study specifically asked for individuals who are familiar with cycle exercise. However some individuals who are not familiar with cycle exercise but routinely participate in other forms of aerobic exercise may be able to meet the qualification criterion of a maximum work rate greater than 300 watts.

CHAPTER 2: REVIEW OF LITERATURE

Overview

Specific equations have been developed to predict VO_2 from steady state activities and are often used to estimate maximal aerobic capacity (VO_2max). This is beneficial because it can be both time consuming and expensive to measure VO_2 through indirect calorimetry (Schoeller, 2007). Prediction of VO_2 is also useful because it can be converted to energy expenditure in calories using a caloric equivalent (Matarese, 1997). Caloric expenditure is an important measurement used by the ACSM for exercise testing and prescription to determine the health and fitness benefits gained from physical activity (ACSM et al., 2010).

The ACSM has advocated the use of their equations in their gold standard publication, the ACSM Guidelines, for treadmill walking and running, cycle ergometry and bench stepping since 1975 and arm ergometry since 1986 (ACSM, 1975, 1986). Every so often, new research has challenged the accuracy of these equations and revisions have been made to many of these predictive equations (Lang et al., 1992; Latin & Berg, 1994; Latin, Berg, Kissinger, Sinnett, & Parks, 2001; Londeree et al., 1997; Maeder et al., 2008; Ruiz & Sherman, 1999; Mookerjee, Surmacz, Till, & Weller, 2005; Swain, 2000). The focus of this research is to extend the use of the ACSM's VO_2 predictive equation for the cycle ergometer to accommodate a more aerobically trained population. The history and theory behind the ACSM cycle ergometer prediction equation are elaborated on in the review to follow, and justifications for the research are explored.

Oxygen Consumption for Energy Production

As the body does more work it requires more energy in the form of adenosine triphosphate (ATP). Adenosine triphosphate is used as energy for biological work, in the forms of a) chemical work to synthesize cellular molecules, b) transportation work to create concentration gradients in extracellular and intracellular fluids, and c) mechanical work or the work of muscular contractions (McArdle, Katch & Katch, 2010; Wasserman, Hansen, Sue, Casaburi & Whipp, 1999). Adenosine triphosphate is created and predominantly replenished by metabolic processes in the body that require oxygen (O_2). The rate of use, or metabolism of ATP, can be measured to classify how hard the body is working (McArdle et al., 2010; Wasserman et al., 1999). Metabolism can be assessed directly by measuring how much thermal energy or heat is lost from the body, in calories, or indirectly by measuring how much O_2 the body is consuming (Brooks, Fahey & Baldwin, 2005). With longer, more intense exercise, the active tissues are doing more work and therefore require more ATP. This elevation in metabolism will produce more heat and require more O_2 to replenish the tissue stores of ATP (Wasserman et al., 1999).

The body only stores enough ATP to power a few seconds of explosive actions and while some energy for the resynthesis of ATP can come from the splitting of a phosphate from phosphocreatine, or the rearranging of two adenosine diphosphate molecules, these sources of ATP replenishment can only supply energy for approximately 10 seconds before a more sustainable method of replenishment is needed (Hochachka, 1985; McArdle et al., 2010). For longer durations of exercise, the body relies on the break down and oxidation of carbohydrates, fats and to a small extent, proteins, that result in further oxidation to produce ATP (McArdle et al., 2010).

Cellular use of O_2 to produce ATP results in an increase in VO_2. As the cells use O_2 for the aerobic production of ATP, the active tissues produce carbon dioxide (CO_2), which must be eliminated as a byproduct of metabolism. Carbon dioxide is present in the blood in the forms of free or dissolved CO_2 (5%), carbonic acid (65%) and bicarbonate (20%) (McArdle et al., 2010). At the lungs there is an abundance of O_2 that acts to dissociate CO_2 from the red blood cells, a process known as the Haldane effect (Brooks et al., 2005). Eventually the byproduct of CO_2 is expired from the body.

Oxygen Consumption with Training

As an individual performs more work, they use more ATP and require more O_2 to replenish energy stores in the body. Therefore, trained individuals who can work at high rates will require more O_2 than untrained individuals. Endurance exercise training elicits several changes that improve the function of cardiovascular, nervous and muscular systems of the body that can all lead to an increase in VO_2max (Martins-Pinge, 2011). Physiologically, VO_2 can be represented as the product of heart rate (HR), stroke volume (SV) and the difference in O_2 concentration between the arteries and the veins, also known as the arterio-venous oxygen difference or oxygen extraction (a-v O_2 difference).

The most notable physiological changes with aerobic fitness occur through central adaptations. An increase of autonomic nervous system capacity and sympathetic tone to the heart and arteries work to increase SV by increasing total blood volume, the speed of ventricular filling, and the force of myocardium contractility (Martins-Pinge, 2011).

Peripheral adaptations associated with aerobic training include an increased blood perfusion by increasing capillary and mitochondrial density and a disassociation of O_2 from hemoglobin in red blood cells increasing the a-v O_2 difference, a relationship that is represented by a shift in the oxy-hemoglobin dissociation curve to the right (Brooks et al., 2005; Kemi & Wisloff, 2010). The final component, maximal HR, contributes the least to an increase in VO_2max with training, because it may decrease slightly or stay the same after aerobic training (Zavorsky, 2000).

Muscular efficiency is the ratio of the rate of work accomplished relative to the energy expended and is increased after aerobic training because of muscular adaptations to exercise (Coyle, 1999; Perot, Goubel, & Mora, 1991). Aerobic training often leads to a change in the properties of muscle fibers in the exercised muscles to display more slow fiber characteristics due to fiber-type transitioning, as well as an increased reflex and neuromuscular excitability (Perot et al., 1991). Trained individuals may also develop more mass in trained muscles (Coyle, 1999). Work is distributed across the increased muscle fiber number and size so these trained muscles can accomplish more work than lesser trained muscles while expending the same amount of energy or consuming the same amount of $O_{2,}$ resulting in greater gross muscular efficiency (Coyle, 1999; Hopker, Coleman, & Wiles, 2007). Due to this increased muscular efficiency and aerobic adaptations, aerobically trained individuals can often work at higher submaximal rates (≈ 400 watts) than lesser trained individuals and possibly be able to work at WR higher than 1,200 kgm/min, which is the upper limit of the accuracy of the ACSM's cycle VO_2

prediction equation (ACSM et al., 2010; Lucia, Hoyos, Santalla, Perez, & Chicharro, 2002; Lucia, Rivero, et al., 2002).

Measuring Oxygen Consumption to Calculate Energy Expenditure

All cellular events, including using ATP for muscular work, produce heat which is given off by the body and can be measured to determine metabolic rate (Brooks et al., 2005). Direct calorimetry is the technique that measures the heat given off by the body, in kilocalories (kcal) in all forms; evaporation, radiation, convection and conduction (Ferrannini, 1988). This is done by completely enclosing an individual in a heat sensitive chamber and measuring the change in temperature in the enclosure. An enclosure like this can be very expensive and space consuming. Alternatively, the method of indirect calorimetry is the process of measuring VO_2 and/or carbon dioxide production (VCO_2) in order to calculate heat production and energy use by the body (Jequier & Felber, 1987).

Oxygen reserves in the body are very small, and the a-v O_2 difference at rest and exercise at moderate intensities remains constant, VO_2 measured at the mouth reflects O_2 used by the tissues, and assuming all of the CO_2 that is produced is a byproduct of energy metabolism, expired gases can be used to calculate the amount of energy produced (Ferrannini, 1988; Jequier & Felber, 1987). Jequier and Felber (1987) explained that because of the first law of thermodynamics, which states energy is neither created nor destroyed, the amount of heat released by oxidative processes or VO_2 and the amount of heat lost from the body, are identical. Jequier and Felber (1987) also explained that all energy dependent processes in the body use the energy given off by the hydrolysis of ATP and that the energy from muscular contractions is not from the direct oxidation of nutrients. The caloric equivalent of one liter of oxygen consumed can range from 4.50 to 5.05 kcal depending on the substrate composition (Brooks et al., 2005).

Indirect Calorimetry Techniques

There are many different indirect calorimetry techniques that exist and have been used to collect and analyze inspired and/or expired gases in order to determine VO_2. Total collection systems such as the Douglas Bag (Oxford, England), which is considered the gold standard for measuring gas exchange, collect all expired air and analyze the O_2 and CO_2 content of the entire unit of air, not allowing for separation of the sample into time increments such as breath-to breath measurements (Crouter, Antczak, Hudak, Della Valle, & Hass, 2006; Levine, 2005).

In contrast to the Douglas Bag, the later developed confinement systems are large air tight enclosures that participants are placed in while their VO_2 and VCO_2 are estimated based on the changes in the concentrations of these gases in the container over time (Levine, 2005). These systems are not usually used to analyze VO_2 during exercise because the containers are expensive and space consuming and would be even more expensive and space consuming if made large enough to contain exercise equipment.

Closed circuit systems, one of the earliest attempts to measure O_2 consumption, are composed of a sealed respiratory gas circuit that participants breathe from and back into, while energy expenditure is calculated from the change in O_2 and CO_2 concentration throughout the session in time increments (Levine, 2005; Matarese, 1997). While these systems are usually more affordable than open-circuit systems, they can easily become inaccurate due to a leak or a change in lung volume (Matarese, 1997).

Most recent technology has relied on open-circuit calorimetry; the air both expired and inspired by participants is analyzed. There are two different variations of open-circuit calorimeters: ventilated open-circuit systems and expiratory collection systems (Levine, 2005). When Crouter et al. (2006) compared two different open circuit systems' measurements of VO_2 to the gold standard of the Douglas Bag method, they found the Parvo Medics TrueOne 2400 (Sandy, UT) was not significantly different ($p < 0.05$) from the Douglas Bag at rest through work rates up to 250 watts; while the MedGraphics VO2000 (St.Paul, MN) was significantly different ($p > 0.05$) from the Douglas Bag. The VO2000 measured a lower VO_2 than the Douglas bag at rest and higher VO_2 at WR of 100-250 watts.

Gas Analysis in Indirect Calorimeters

Oxygen consumption can be defined as the difference between the amount of O_2 inhaled minus the amount of O_2 exhaled. In order to determine the amount of O_2 that is both inspired and expired, both the volume and fractional composition of O_2 in the air in both situations must be known. Samples of both the room air and collected air are analyzed to reveal what fractions of the inspired and expired air respectively are O_2 and CO_2. The fractional compositions and the volume of air expired are measured by the analyzing system. While the volume of air inspired is not measured, it is calculated by the gas analysis system using the fractional composition of nitrogen (N_2) and the Haldane transformation equation (McArdle et al., 2010). The Haldane transformation equation, which was proven accurate by Wilmore and Costill (1973), assumes that N_2 is neither created nor consumed by the body. As a result, the amount of N_2 inhaled should equal the amount of N_2 exhaled (Beam & Adams, 2011; Haugen, Chan, & Li, 2007).

Predicting Oxygen Consumption

Collecting expired gases to measure VO_2 at steady state can involve expensive equipment and may be uncomfortable for participants because of the cumbersome mouthpiece and head gear, so methods have been developed to predict individuals' VO_2 without the need to collect and analyze the air they breathe (Hawley & Noakes, 1992; Ross, Murthy, Wollak, & Jackson, 2010). Furthermore, since HR and VO_2 have a linear relationship, as HR increases, VO_2 should increase at the same rate (ACSM, 1975). By progression of WR and measured HR response, the progression of VO_2 can be predicted, which is often achieved using either a nomogram (Astrand & Ryhming, 1954) or equation developed from this linear relationship (ACSM, 1975, 1980, 1986; ACSM, Franklin, Whaley & Hawley, 2000; ACSM et al., 1995, 1991, 2010, 2006). Prediction equations exist for many different exercise modalities such as treadmill walking and running, aerobic dancing, arm ergometry, elliptical training, bench stepping and finally, the focus of this research, leg cycling (ACSM et al., 2010; Dalleck, Kravitz, & Robergs, 2006; Olson, Williford, Blessing, Wilson, & Halpin 1995).

Oxygen consumption prediction equations are comprised of estimations of the resting, horizontal and vertical or resistance components of exercise. When specifically looking at the current ACSM equation for predicting the energy expenditure of leg cycling, VO_2 can be estimated at any point in time during an exercise bout where a steady state HR is measured, just by inserting the WR and the participants BW into the equation.

A steady state HR is often defined as a change of less than six beats per minute (BPM) (ACSM, et al., 1995; Matarazzo, Weiss, Herd, Miller, & Weiss, 1984). It demonstrates when participants have reached a temporary equilibrium between O_2 supply and demand, and currently the heart does not need to work any harder to maintain the current WR. Since VO_2 and HR are linearly related a measured steady state HR also represents a steady state of VO_2 (ACSM, 1975).

Predicting Maximal Oxygen Consumption

Exercise tests are often administered to determine individual physiological responses to stress and VO_2max. Although VO_2max can be influenced by several characteristics such as age, BW, muscle mass, or gender, it is useful to classify individual aerobic health or fitness or to track their progress in a training program (Neder, Nery, Silva, Anderoni, & Whipp, 1999). In order to determine an individual's VO_2max, the individual must work to failure, and because of this, these tests are known to be uncomfortable and may even be dangerous for the participant if they have any underlying risk factors that could be contraindications to exercise (ACSM et al., 2010). These tests can also be time consuming and costly for the researchers or clinicians administering them (Schoeller, 2007). While there are some instances where a GXT is necessary for diagnostic purposes in the diseased or at risk population, there are many cases in the apparently healthy population when the cost and discomfort of a true GXT is not necessary and VO_2 prediction equations are used to predict VO_2max.

The maximal rate of O_2 consumption can be predicted after the completion of a submaximal graded exercise trial (SXT). Using the last two steady state HR from each stage of the SXT that were above 110BPM and the WR that elicited these HR, a graph is set up with WR on the abscissa (x axis) and HR on the ordinate (y axis). The HR responses are plotted against the WR that elicited them (■). Then these two points are connected and the line is extrapolated (dash line) to the age predicted maximum HR (220-age) (solid horizontal line). From this point (O) a line is drawn straight down to meet the "maximal WR" value on the x axis (X). The maximal WR value is then used in the prediction equation in order to find the VO_2max (see Figure 1).

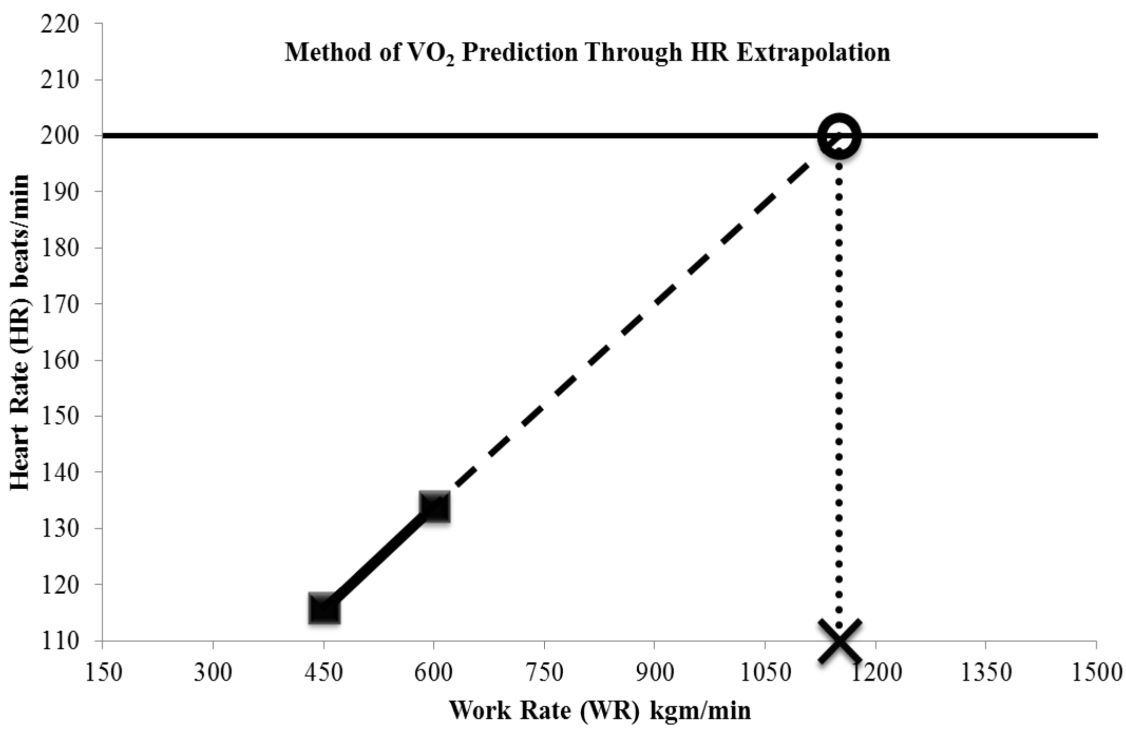

Figure 1. Predicting maximal oxygen consumption.

The eighth edition of the ACSM Guidelines state for this technique and equation to most accurately estimate VO_2max, the following assumptions must be true: A steady-state HR is obtained for each exercise WR and is consistent each day; a linear relationship exists between HR and WR; the maximal work load is indicative of VO_2max; the maximal heart rate (HRmax) for a given age is uniform; mechanical efficiency (VO_2 at a given WR) is the same for everyone; and, the participant is not on medications that alter HR (ACSM et al., 2010). The ACSM Guidelines also note that the cycle prediction equation is most accurate when WR between 300 and 1,200 kgm/min are used (ACSM et al., 2010). Unfortunately, there are few instances where all of these assumptions are true, and while a SXT may be more comfortable and affordable than a GXT, it is only an estimation of VO_2max.

Linear Relationship of Work Rate and Oxygen Consumption before Anaerobic Threshold

Research suggests one difficulty in developing a prediction equation is that WR and VO_2 may only have a linear relationship until an individual reaches their anaerobic threshold (AT) (Lucia et al., 2002). Often the AT is estimated by the accumulation of lactate, a byproduct of ATP production when glycogen or glucose is used as the predominant fuel substrate and there is a limit for aerobic metabolism. Lactate threshold (LT) is the point during an exercise bout where the lactate begins to accumulate. The lactate concentration in the blood is either remaining constant or beginning to increase because the rate of lactate production is catching up to and beginning to pass the rate of the clearance of lactate (Faria, Parker, & Faria, 2005).

The AT can also be estimated using the ventilatory threshold (VT). Ventilatory threshold is identified as the point at which there is a distinct increase in VCO_2 without a matching distinct increase in VO_2. The difference in the rise of these two variables occurs due to an increased expiration of CO_2 as a result of the buffering of byproducts of anaerobic metabolism. The CO_2 is a byproduct of the bicarbonate buffering system that is working to clear the blood of the hydrogen ions (H^+) that result from the breakdown of lactic acid ($C_3H_6O_3$). These hydrogen ions are combined with carbonic acid (HCO_3^-). As a result water (H_2O) and CO_2 are produced (Hopker, Jobson, & Pandit, 2011).

The rise in VO_2 during increased WR can be divided into a fast and a slow component. The fast component of VO_2 near the onset of exercise, tends to increase linearly with WR, and lasts until an individual reaches their AT. The slow component of VO_2 is seen after AT, and is not linearly related to WR. The slow component represents a gradual nonlinear increase in the rate VO_2. However, research has shown that the magnitude and duration of the slow component of VO_2 is reduced with endurance training due to an increase in VO_2 as well as a later onset of anaerobic threshold (Gaesser, 1994; Xu & Rhodes, 1999). Often in professional cyclists, the slow component of VO_2 is represented by a nonlinear decrease in the relationship of VO_2 and WR (Lucia et al., 2002).

Equations used to predict VO_2 are based on a linear relationship between VO_2 and WR, which is true during the fast component, but not the slow component of VO_2 where an individual begins to approach VO_2max. A group of researchers, whose equation was later used to help establish the current ACSM equation, suggested that prediction equations that rely on the linear relationship of VO_2 and WR should not be used for workloads that exceed AT (Latin, Berg, Smith, Tolle, & Woodby-Brown, 1993). If this is the case, then these equations should not be used to predict VO_2max, even if the predicted maximal WR (WRmax) is in the "most accurate" range. Even the most recent edition of the ACSM Guidelines provide the warning that their equations are most accurate when estimating VO_2 at submaximal steady-state workloads from 300-1,200 kgm/min, and that caution must be used when using these equations for extrapolated workloads outside of this range.

Time to Reach Anaerobic Threshold in an Endurance Trained Population

There are several proposed reasons why the duration of slow component of VO_2 in the endurance trained populations is less than in an untrained population, including decreased catecholamine and potassium concentrations, increased time to reach AT, greater cardiorespiratory function, and ability to continue to recruit efficient motor units as exercise continues (Lucia, Hoyos, & Chicharro, 2000). Due to the shortening of the nonlinear slow component of VO_2, an equation that relies on the linear relationship between VO_2 and WR would be more accurate in predicting VO_2max in the aerobically trained population when compared to the lesser trained population.

History of ACSM Oxygen Consumption Prediction Equation

The VO_2 prediction equations published in the ACSM Guidelines have evolved over time for a few different modalities, including the cycle ergometer (see Figure 2) (Swain, 2000). All of the equations and their updated versions are constructed as slope equations, or $y = mx + b$, with "m" being the slope of the line representing the relationship between VO_2 and WR, "b" the y-intercept representing the resting and horizontal components of VO_2, and finally with "x" and "y" representing the changing variables (WR and VO_2 respectively).

The focus of this study is the VO_2 prediction equation used for the cycle ergometer, and, as previously mentioned, the ACSM equation has evolved over time. The first and second editions of the ACSM Guidelines presented the following equation:

VO_2 (ml/min) = WR (kgm/min) x 2.00 (ml/kgm) + 300 (ml/min).

The slope of this equation, 2.00 ml/kgm consists of the 1.80 ml/kgm work of pedaling a cycle ergometer, and the remaining 0.20 ml/kgm represents the internal friction work of the muscles being used in the legs. The y-intercept in this equation was 300 ml/min, which represented the metabolic cost of rest (ACSM, 1975, 1980).

An updated version of the prediction equation appeared in the third, fourth and fifth editions of the ACSM Guidelines:

VO_2 (ml/min) = WR (kgm/min) x 2.00 (ml/kgm) + {3.50 (ml/kg/min) x BW (kg)}.

The slope of this version of the equation stayed the same as the original, but the y-intercept changed. The 3.50 ml/kg/min, which appears as part of the y-intercept, still represents the metabolic cost of rest, but was now relative to an individual's BW (ACSM, 1986; ACSM et al., 1995, 1991). The fourth edition of the ACSM Guidelines supported this change by explaining that BW is a major determinant of VO_2. If a person has a greater BW they are more likely to have more muscle mass, and as explained earlier, the more muscle a person uses, the more O_2 will be consumed.

In the early 1990's, several groups of researchers set out to test the accuracy of the ACSM cycle prediction equation. Several of these groups determined the existing equation consistently underestimated the actual value of VO_2 (Lang et al., 1992; Latin & Berg, 1994; Swain, 2000). Londeree et al. (1997) saw a different issue, reporting that several researchers before them discovered that the relationship between VO_2 and WR was not linear and decided a closer look needed to be taken regarding WR at different workloads and speeds.

In an effort to fix these problems, Lang et al. (1992), Latin and Berg (1994) and Londeree et al. (1997) each created their own equation by running a regression analysis between the actual VO_2 and the WR of their participants. The slopes of these equations were all lower than the existing equations. The slopes of the research developed equations were as follows: 1.90 ml/kg (Lang et al., 1992), 1.60 ml/kg (Latin & Berg, 1994) and finally 1.73 ml/kg (Londeree et al., 1997; Swain, 2000). The equations' y-intercepts were all higher than the existing equation because they now included the O_2 cost of unloaded cycling, as well as the pre-existing component used to measure resting metabolic rate relative to BW (3.50 ml/kg/min x BW) (Swain, 2000). In the equations computed by Lang et al. (1992) and Latin and Berg (1994), the participants pedaled at 60 revolutions per minute (RPM), which resulted in an O_2 cost of 260 ml/min for males age 19-39 years (Lang et al., 1992), 205 ml/min for females age 21.20-31.80 years (Latin & Berg, 1994), and while pedaling at 50 RPM, 245 ml/min in a study of both genders age 18.5-33 years (Londeree et al., 1997). The first two studies (Lang et al., 1992; Latin & Berg, 1994), restricted their participants to the amount of cycling experience they could have to less than three times per week, 15 minutes per session and to have never cycled more than 50 miles per week for 4 consecutive weeks. Meanwhile the study conducted by Londeree et al. (1997), studied participants whose fitness status ranged from sedentary to competitive cyclists.

In response to these studies (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997), the ACSM published a revised cycle VO_2 prediction equation (ACSM et al., 2000; Swain, 2000). The revised and current version of the equation first appeared in the sixth edition of the ACSM Guidelines:

VO_2 (ml/kg/min) = {(1.80 (ml/min) x WR (kgm/min)) / BW (kg)} + {3.50 (ml/kg/min) + 3.50 (ml/kg/min)}.

This equation is structured slightly different from the previous two versions. The “x” component that is multiplied by the slope (“m”) has changed the most because it is now the quotient of two variables, the WR and BW of the individual that is working on the ergometer. The y-intercept, or “b,” however, is not relative to the individual and is now uniform among people. The first 3.50 ml/kg/min represents the VO_2 of rest, while the second 3.5 ml/kg/min represents the VO_2 of unloaded cycling.

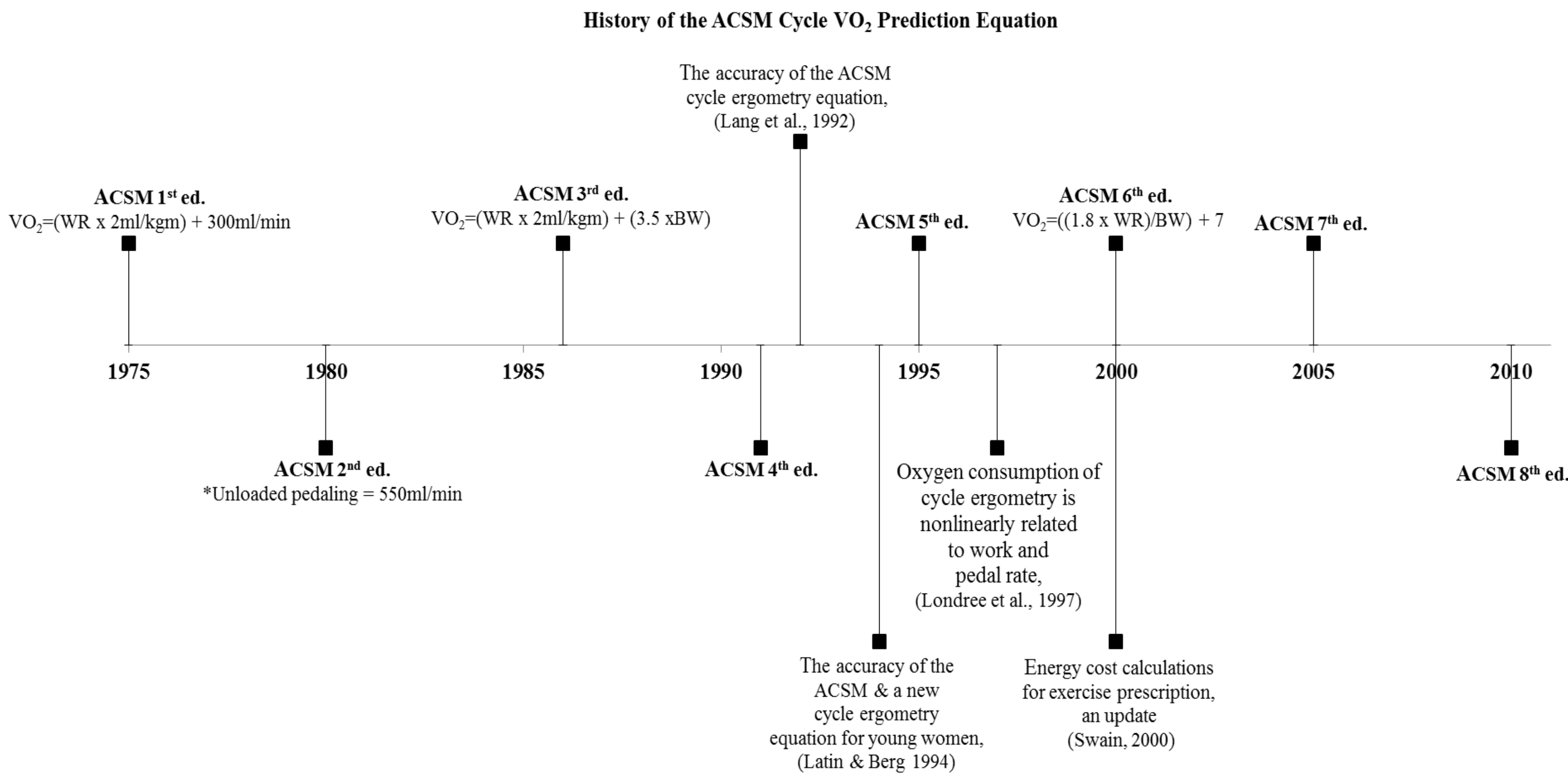

Figure 2. Timeline of the ACSM VO_2 prediction equation for the cycle (Adapted from ACSM, 1975, 1980, 1986; ACSM et al., 2000, 1995, 1991, 2010, 2006; Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997; Swain, 2000).

Limitations to ACSM's Cycle Oxygen Consumption Prediction Equation

Applicable Work Rate

The ACSM cycling prediction equation is said to be "most accurate" for work rates between 300 and 1,200 kgm/min (50-200 watts) (ACSM et al., 2010). While this range may be acceptable for the average healthy population, a range of 300-1,200 kgm/min may represent the lower end of submaximal WR for a more athletic population with a greater muscle mass and greater aerobic capacity. Some athletic individuals and trained cyclists can pedal around WR of 2,500 kgm/min (400 watts) for an extended period of time (Lucia, Hoyos, et al., 2002).

This stipulation causes a more common problem when the equation is used to predict VO_2max. When the HR is extrapolated to meet the age predicted max HR, if the determined WR is outside of this range the prediction equation is said to not be "most accurate" (ACSM et al., 2010). This equation may not be ideal for calculating steady state VO_2 or VO_2max in more athletic, aerobically fit populations who can work at higher intensities. More aerobically fit populations, relative to lesser trained individuals, have less of a HR response, because of lower exercise HR at a given WR and higher VO_2max values (Brooks et al., 2005).

CHAPTER 3: METHODS

Overview of Experimental Design

The objective of this study was to create a new equation to predict VO_2 for cycle ergometer exercise at WR both below and above 200 watts (1,200 kgm/min). Individuals who could maximally cycle above 300 watts, determined by a participation in a GXT, were asked to participate in two individualized submaximal exercise trials (SXT) while their expiratory gases were collected. A regression analysis between WR and associated VO_2 from the SXT were used to develop the new prediction equation.

Participants

Men and women, 18-55 years of age, who were familiar with cycle exercise and aerobically exercised at least 3 days a week, were recruited to participate in this study. Exclusion criteria included: pregnancy; any known cardiovascular, metabolic or pulmonary diseases; any orthopedic conditions that would limit their cycling ability; or, having an illness during the week before arriving for the initial visit. If being ill one week prior to testing was the only exclusion criteria met by the participant, they were asked to participate at a later date.

Recruited participants arrived to all sessions fasted for 4 hours and refrained from caffeine, alcohol, nicotine, nutritional supplements, exercise and physical activity above their typical daily routine for the previous 12 hours. Upon arrival for the initial session all participants were informed of the purpose and procedures of the study, and after given the opportunity to ask questions, they were asked to sign an informed consent document that had been approved by the Ohio University Institutional Review Board.

Procedures

Orientation and Maximal Graded Exercise Test Visit

Upon explanation of the test and signing the informed consent document, participants were asked to complete a health history questionnaire to determine if they possessed any contraindications to submaximal or maximal exercise (ACSM et al., 2010). The participant was considered “low risk” if they had one or no cardiovascular risk factors and were allowed to continue. Next, after sitting quietly for at least 5 minutes, participants had their resting seated blood pressure measured. If the individual was hypertensive (systolic > 140 mmHg or diastolic > 90 mmHg), they were excluded from the study. Their height and weight was then measured and participants’ body mass index (BMI) was calculated. If participants had a BMI greater than or equal to 30 kg/m^2, they were not allowed to participate.

The eligible participants were fitted with a heart rate monitor strap around their chest at the level of the xiphoid process (Polar A1, Lake Success, NY). The chest strap was synched with several heart rate monitors as well as the metabolic cart. A few seconds before HR was collected throughout the GXT, participants were asked to return their hands to the handle bars, if not already there, so consistent HR measurements could be collected. Age-predicted heart rate maximum (207 – (0.70 x age in years)) was calculated for each participant before the initiation of the GXT. The Borg rating of perceived exertion (RPE) scale (Borg, G., 1982) was then explained and grounded the same for each participant.

A Lode Excalibur sport cycle ergometer (Lode BV Excalibur Sport 925900, Gronigen, The Netherlands) was fitted to each participant with the seat height adjusted so that it elicited a knee bend of five degrees when the pedal was in its lowest position (ACSM et al., 2010). The appropriate seat height and preferred handlebar position was recorded so it could be replicated during the subsequent SXT if the participant qualified.

The participant was then fitted with a mouthpiece and nose clip to collect expired air. This air was analyzed by a metabolic cart (ParvoMedics, Sandy, UT) in 30-second intervals. The metabolic cart had been previously calibrated for gas concentrations and flow rate according to the manufacture's specifications, no more than 45 minutes before each trial initiation. All testing took place in the Exercise Physiology Lab at Ohio University in Athens, Ohio.

All participants underwent a GXT protocol that was developed by the researchers to elicit VO_2max within 25 minutes. For men the protocol started at 100 watts and increased by 30 watts every two minutes, whereas for women, the protocol started at 75 watts and increased by 30 watts every two minutes. The test only took longer than 25 minutes for 1participant because he had a very high WRmax, reaching the 13^{th} stage at 490 watts.

The cadence was freely chosen by the participant and was to remain above 40 RPM. The participant was also asked to remain seated or the test was ended. Each participant was asked if they like strong verbal encouragement during exercise. If they answered "yes," positive encouragement was given to them especially near the end of their test. All participants were asked to continue the test until voluntary exhaustion, and the GXT was only stopped prior to participant failure if any absolute indications for stopping the test arose, or the participant's cadence fell below 40 RPM (ACSM et al., 2010). When the tests ended, participants actively cooled down for at least 5 minutes.

A GXT is considered a true maximum if three of the following four criteria are met: a) respiratory exchange ratio greater than 1.10; b) HR within 10 beats per minute of age predicted HRmax; c) RPE of 18 or above; d) oxygen plateau with an increase in workload, which has previously been identified as a change in VO_2 of less than or equal to 2.10 ml/kg/min (Howley, Bassett, & Welch, 1995), or even smaller, as less than 50 ml/min (ACSM, 2010; Howley, Bassett, & Welch, 1995). If participants' WRmax met the minimum criterion of 300 watts they were invited back to complete two randomized SXT. The SXT were scheduled on two different days with at least 2 but no more than 10 days apart with both trials within 3 weeks of the initial testing day. Each of the three tests occurred at the same time of day ± two hours. Only 1 participant could not schedule his subsequent test within 10 days. His first SXT was 7 days later than his GXT and his second SXT was 14 days after his first SXT. Considering both tests were performed within 3 weeks of the GXT, his results were included in the analysis.

Submaximal Exercise Test Visits

Participants arrived for both SXT at the same time of day (± 2 hours) as the initial GXT. Again, they fasted for 4 hours and having avoided caffeine, alcohol, nicotine, nutritional supplements, and exercise and physical activity above their typical daily routine for 12 hours. Body fat, by skinfold thickness, was measured at three select sites prior to the first SXT, according to standard procedures, and used for descriptive purposes only (ACSM et al., 2010). On women, these sites included the back of upper arm (triceps), hip (suprailiac crest) and mid-thigh, whereas for men, the sites included the chest (pectoralis), abdomen (umbilicus) and mid-thigh. Pinches of the skin (cutaneous membrane) and the subskin (subcutaneous) fat were held for approximately 5 seconds while subsequent measurements with a hand-held caliper occurred. These assessments took place rotating from one site to the next for a total of two to three times per site, allowing at least 1 minute between each pinch. The sum of these sites was recorded to the nearest millimeter.

Qualified participants completed two subsequent SXT in random order while their ventilatory data was collected as described above for the GXT. The exercise protocols consisted of six stages, each of increasing intensity beginning at either 35 or 45% and increasing up to 85 or 90% of their WRmax. The first two stages served as a warm up (i.e., 35 and 45% for trial 1, and 40 and 50% for trial 2) (see Figure 3). Each stage lasted between 5 to 10 minutes and between the last four stages, a low intensity active recovery period was provided for 3 to 5 minutes, with the length determined by the participant. During this recovery period the participant could cycle (30% of their WRmax) or they could get off of the bike and walk or stretch. Also during this recovery period, participants were allowed to remove their mouthpiece and get a drink of water.

At each WR of the SXT, participants were allowed to freely choose their cadence in the range of 60-100 RPM. Each stage was endured until steady state VO_2 was reached. To determine this point, the average of VO_2 was collected every 30 seconds. The difference between consecutive 30 second measurements was calculated. As suggested by previous research, if the difference was less than or equal to 50 ml/min between the third and fifth minute of the stage, the participant was said to be at steady state and they were moved to the next stage (or recovery period if this was during the third, fourth or fifth stages, or the test was ended if this was during the sixth stage) (Lang et al., 1992). To prevent fatigue, if the participant had not reached steady state by the fifth minute of the stage the difference in VO_2 that would qualify as steady state was expanded to a difference of less than or equal to 100 ml/min between the fifth and seventh minute. Even if it took participants more than 5 minutes in a stage to reach steady state the larger VO_2 difference of 100 ml/min was only needed 15 out of the 348 stages and was never needed more than twice in the same participant. If steady state VO_2 was not reached in 7 minutes, the exercise session was ended, and only the stages where steady state was reached were included in the statistical analysis. However, no participant failed to reach steady state in 7 minutes and every participant reached steady state in all twelve stages. The average value of the two consecutive 30 second VO_2 readings that resulted in a steady state difference was considered the steady state value and statistically analyzed.

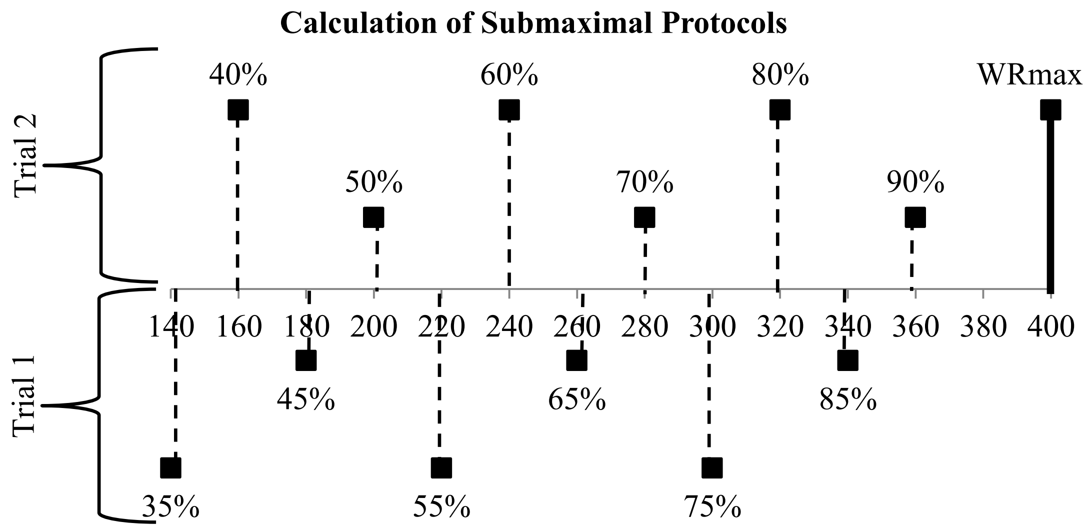

Figure 3. Example of submaximal protocol calculation by percentages of WRmax.

When each SXT was over the participants completed a cool-down of no less than 5 minutes at a low intensity. Therefore, the total time on the cycle for each trial was between 32 and 62 minutes.

Statistical Analysis

Sample Size

A very strong relationship exists between VO_2 and WR. Londeree et al. (1997) reported this relationship having a R^2 of 0.94. Using a chart by Algina & Keselman (2000) for multiple regression and the equation $R^2 - R_c^2 = \varepsilon$, we calculated our projected number of participants. Regarding this equation R^2 is the relationship seen in the population (0.94; Londeree et al., 1997), R_c^2 is the cross validity R^2, which is the R^2 expected in a new sample, and ε is the size of the desired difference between the R^2 and

R_c^2 or the expected shrinkage (Stevens, 2007). We set the ε at 0.05 and the desired probability of this relationship (**γ**) at 0.95 resulting in the projected N needed of 25.

Creation of a New Equation

Participants' WR and VO_2 accomplished during the SXT were analyzed by simple regression to develop a new equation, referred to as the OU equation that will be used to predict VO_2 from WR above 200 watts.

After the initial analysis of data including all collected data points, data was sorted for WR below and above 200 watts and also separated by WR below and above participants VT, and again analyzed by regression.

The 99.9% confidence interval of both the slope and y-intercept of the OU equation were also received through statistical analyses. These confidence intervals represent the range that includes the average of 99.9% of the population based on the data we collected from our sample.

CHAPTER 4: RESULTS

A total of 53 potential participants were recruited through the use of fliers, e-mails and word of mouth to participate in this study. All were screened for their health history and contraindications to exercise and were cleared to complete the GXT. Thirty (55.56%) individuals achieved a WRmax greater than or equal to 300 watts during the GXT and qualified to continue with the study. Of these 30 qualified participants 29 were male and 1 was female. One male participant chose not to return for SXT (personal reasons), therefore, 29 of the 30 qualified returned and completed the remaining tests and 12 data points were collected from each of these individuals resulting in 348 total data points which were included in subsequent analyses.

The descriptive data of the 29 qualified and analyzed participants are presented in Table 1. As a note, the 1 female included in the analysis had the lowest height and the highest percentage of body fat of all of the participants analyzed and therefor extended the range of these variables. The height for men only had a range of 1.71-1.89 meters and the percent body fat for only men was between 4.25-15.48%.

Table 1

Descriptive Data (participants = 29)

Measurement	Mean	Standard Deviation	Range
Age (yrs)	30.10	± 10.93	20-54
Height (m)	1.80	± 0.05	1.66-1.89
Weight (kg)	78.29	± 8.11	63.70-97.00
BMI	24.17	± 1.69	20.90-28.04
Percent Body Fat	9.14	± 3.78	4.25-20.16
VO_2max (ml/kg/min)	55.17	± 5.27	48.02-70.58
VO_2max (L/min)	4.31	± 0.49	3.42-5.69
WRmax	361.13	± 37.81	311.50-472.75
Average Submaximal Cadence	84.46	± 8.94	64.88-100.22
% of VO_2 at VT	71.21	± 5.28	61.00-82.00
% of WRmax at VT	70.01	± 6.71	57.86-79.91

A simple regression analysis was used to create an equation that would use WR in watts relative to body weight (WR/BW) to predict relative VO_2 (ml/kg/min) for cycle ergometer exercise. To do this, the dependent variable was relative steady state VO_2 (ml/kg/min) while the independent variable was WR/BW (watts/kg). All data points were used (participants = 29; n = 348) to create an equation because we were seeking to create an equation that could be used with both genders. Due to data only being collected from

1female, we wanted to determine if there would be a difference in the equation if we did not include her. As a result we then analyzed only the data points from the men (participants = 28; n = 336) to create a regression equation. The powers of the equations were very similar. When all data points (n = 348) were used the equation created had a Pearson's product moment correlation coefficient (r) of 0.9785, an (R^2) of 0.9574, an adjusted R^2 of 0.9573, an R_c^2 of 0.9566 and a standard error of the estimate (SEE) of 1.992. When only the data points from men (n = 336) were used the equation had an r of 0.9784, R_2 of 0.9572, an adjusted R_2 of 0.9571, and an SEE of 2.005. Previous research statistics suggests these values are considered "powerful" or of "high strength of association" (Cohen, 1988). The focus of this research was to create an equation for trained individuals, without consideration of gender; therefore, the data obtained from the 1female participant was included for all subsequent analyses and the resulting equation was referred to as the OU equation.

The y-intercept of the OU equation was determined to be 4.522 with a standard error (SE) of 0.375 ($t = 12.051$, $p \leq 0.001$). The slope of the OU equation was calculated as 10.941 with a *SE* of 0.124 ($t = 88.188$ $p \leq 0.001$). These results give rise to a new equation to predict VO_2 from WR between 109 and 425 watts, as follows:

VO_2 (ml/kg/min) = 10.941 (ml/watt) (WR (watts) / BW (kg)) + 4.522 (ml/kg/min).

The confidence interval for both the slope and the y-intercept were calculated at 99.9%. The confidence interval for the y-intercept was 3.277 – 5.768, and 10.529 – 11.353 for the slope ($p \leq 0.001$) (see Table 2).

Table 2

Confidence Intervals of Coefficients

Unstandardized Coefficients					99.9% Confidence Interval	
B	Standard Error	β	*t*	Sig.	Lower	Upper
4.522	0.375		12.051	0.000	3.277	5.768
10.941	0.124	0.978	81.188	0.000	10.529	11.353

Work Rate

Linear regression was used to determine if there was a difference in equations if the data was separated by WR below and above 200 watts. The regression was run with relative VO_2 as the dependent variable and WR/BW, a variable that sorted WR, and an interaction variable as independent variables. Neither the sorted (y-intercept) nor interaction (slope) coefficients were significant (t = -1.090, 1.402, p = 0.276, 0.162, respectively, SEE = 1.990) (see Table 3).

Table 3

Difference in Slope and y-Intercept of Below and Above 200 Watts

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients β	*t*	Sig.
(Constant)	5.929	0.963		6.158	0.000
Relative WR (WR/BW)	10.215	0.465	0.914	21.976	0.000
Above or Below 200watts	-1.349	1.238	-0.068	-1.090	0.276
Interaction 200watts	0.723	0.516	0.130	1.402	0.162

Ventilatory Threshold

A separate linear regression analysis was used with relative VO_2 as the dependent variable and WR/BW, a variable that sorted data as either below or above VT, and an interaction variable as independent variables. Again, neither the sorted (y-intercept) nor the interaction (slope) coefficients were significant (t = 0.069, 0.041, p = 0.945, 0.967 respectively, SEE = 1.998) (see Table 4).

Table 4

Difference in Slope and y-Intercept of Below and Above VT

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients β	*t*	Sig.
(Constant)	4.654	0.560		8.314	0.000
Relative WR (WR/BW)	10.876	0.226	0.973	48.196	0.000
Above or Below VT	0.091	1.317	0.005	0.069	0.945
Interaction VT	0.016	0.389	0.003	0.041	0.967

Comparison of Measured VO_2 and VO_2 Predicted from ACSM Equation

When the measured steady state VO_2 were compared to VO_2 values predicted by the ACSM version of the prediction equation by a paired samples *t*-test, there was a significant difference between the two. There was a mean difference of -2.694 ml/kg/min with a standard deviation of 1.991 ($t = -25.250$, $df = 347$, $p \leq 0.001$).

Comparison of Predicted Values from OU and ACSM Equations

A paired samples *t*-test was run to compare the values predicted by the OU equation to the VO_2 values predicted by the current version of the ACSM equation (ACSM et al., 2010). The mean difference of -2.694 ml/kg/min with a standard deviation of 0.064 was significant ($t = -779.988$, $df = 347$, $p \leq 0.001$).

Figure 4 shows all the measured data points and all of the predicted VO_2 using the ACSM equation, along with a line representing the slope of both the OU and ACSM VO_2 prediction equations (see Figure 4.).

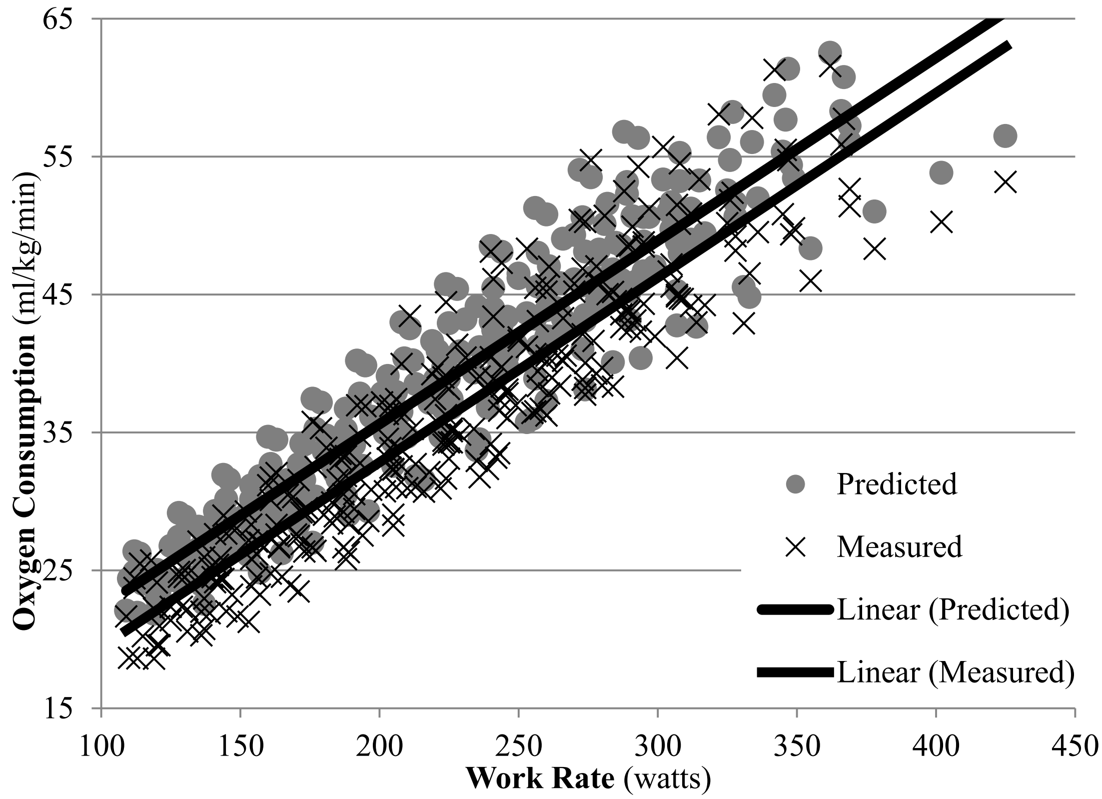

Figure 4. Measured VO_2 and VO_2 predicted using the ACSM prediction equation.

Comparison of Cadence Between Trials

A paired samples *t*-test was run between the cadences of trial one versus the cadences of trial two. There was no significant difference in mean cadence between the two trials (mean difference = 0.892 RPM, $t = 0.869$, df 28, $p = 0.392$).

CHAPTER 5: DISCUSSION

The purpose of this study was to create an equation that would be accurate at predicting VO_2 while working on the cycle ergometer at WR both below and above 200 watts in an aerobically trained population. Oxygen consumption prediction equations are beneficial because they allow prediction of an individual's VO_2 and caloric expenditure without costly, time consuming, uncomfortable laboratory procedures. With the accuracy of the current ACSM prediction equation for the cycle limited to 200 watts, the more aerobically fit population needed an equation that was accurate into the range of power outputs where they commonly work. The data confirmed the hypothesis, because an equation was created with an R^2 of 0.9574 to predict VO_2 from WR below and above 200 watts. With an r being greater than 0.50 and an R^2 being greater than 0.25, both statistical values are considered "large." The r and R^2 values of this analysis suggested a high correlation between VO_2 and WR/BW (Cohen, 1988).

Components of the OU Equation

Using all of the data points collected, the formula: VO_2 (ml/kg/min) = 10.941 (ml/watt) (WR (watts) / BW (kg)) + 4.522 (ml/kg/min) was created and can be used to predict relative VO_2 from WR/BW. The r value (0.9785) depicts the relationship or correlation of VO_2 and WR/BW. This represents a large positive correlation between the two variables. The R^2 value of 0.9574 reflects that almost 96% of steady state VO_2 can be explained by WR/BW in another sample (Cohen, 1988). The adjusted R^2 value of 0.9574 suggests that this model will work just as well when applied to the population, while the

R_c^2 value of .9566 suggests that this model will also work well in a separate sample (Cohen, 1988; Stevens, 2007).

The 99.9% confidence interval for the y-intercept and slope of the OU equation were then calculated. Then the ACSM equation was converted from using kgm/min as the unit of work to using the units of watts. This was done by multiplying the slope (1.80 ml/kgm) by 6.12. The ACSM equation could then be written as VO_2 (ml/kg/min) = (11.016 (ml/watt) x WR (watts) / BW (kg)) + 7.000 (ml/kg/min). The y-intercept of the ACSM equation was not included in the confidence interval of the OU equation. This conveys that the y-intercepts of the two equations are significantly different from one another. On the other hand, the confidence interval of the slope of the OU equation did include the slope of the ACSM equation, therefore the slopes of the two equations are not significantly different from one another. This represents a 99.9% chance that the slope, or the relationship between VO_2 and WR, of the population is within the specified interval and the y-intercept is not (Aron, Aron, & Coups, 2005).

Difference between Predicted Values of the OU and ACSM Equation

Before the ACSM prediction equation was updated to its most recent form, several groups of researchers set out to test the accuracy of the existing equation. Three research groups independently determined that the published equation for cycling at the time of their work was inaccurate so they used their data to create equations (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997). When the predicted values of the ACSM and the OU equations were compared by a paired samples *t*-test, the results revealed a mean difference between the two equations of -2.694 ml/kg/min with a standard deviation of 0.064 (t = -779.988, df = 347, $p \leq 0.001$).

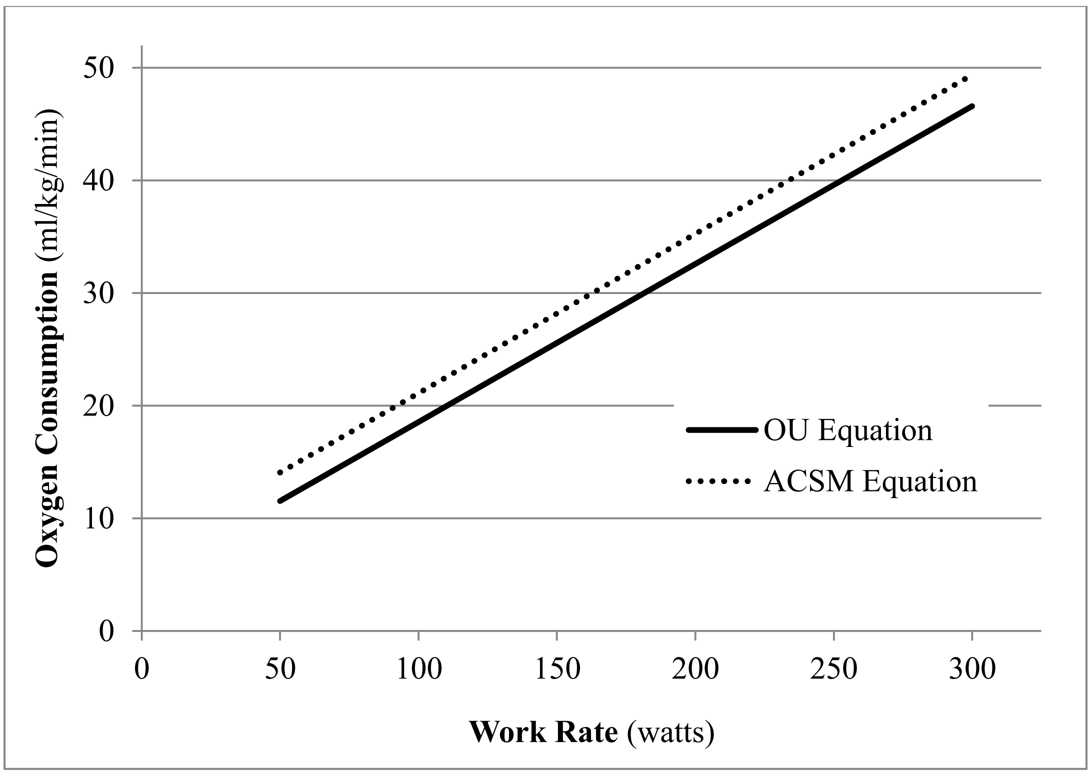

Figure 5. Linearity in the slope of the prediction of VO_2 using both the OU and ACSM prediction equations.

To further explain this difference of -2.694 ml/kg/min between equations an example has been provided (see Table 5). A 78 kg individual (coincidentally, was the mean body weight of participants in this investigation) working at 50 watts, would have a predicted VO_2 of 11.54 ml/kg/min with the OU equation. The current ACSM equation would predict a value of 14.06 ml/kg/min. These estimates are different by 2.53 ml/kg/min. When this VO_2 difference is translated to kcals/min by assuming 5 kcal per L of O_2 consumed, this is a difference of 0.99 kcals/min between equations. If this individual works for 1 hour, this would result in an overestimation of 59.40 kcal; and if they exercised at the same WR 5 days a week, they would have a difference of 297.00 kcals per week. These errors in prediction might be a serious issue for cyclists. Elite athletes are often trying to maintain weight, not trying to gain or lose, especially during the cycling season. Weight loss can be very detrimental towards performance in these athletes and balancing their caloric intake and output is very important (Saarni, Rissanen, Sarna, Koskenvuo, & Kaprio, 2006). This difference in VO_2 and kcal expenditure between the two equations grows with an increase in WR/BW. This error reinforces the need for an updated equation.

Table 5

Differences Between Equations

Work Rate (watts)	50	100	150	200	250	300
OU Equation (ml/kg/min)	11.54	18.55	25.56	32.58	39.59	46.60
CSM Equation (ml/kg/min)	14.06	21.12	28.19	35.25	42.31	49.37
Difference (ml/kg/min)	-2.52	-2.57	-2.63	-2.67	-2.72	-2.77
Percent Difference in VO_2	19.74	12.98	9.76	7.87	6.64	2.88
Difference* (kcals/min)	-0.983	-1.00	-1.03	-1.04	-1.06	-1.08

*kcal/min were calculated using the sample average body mass (78kg) and 5.00 kcal/L of oxygen.
Difference refers to the difference between estimated values between the OU and ACSM equations.

Difference in y-Intercept

As demonstrated by the confidence interval, the y-intercept of the OU equation (4.522 ml/kg/min) is significantly different from the ACSM equation's y-intercept (7.00 ml/kg/min). In developing the most current ACSM equation, Swain (2000) set the y-intercept as a combination of the results from the previous literature (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997). The ACSM y-intercept is explained as having two components, each equaling 3.50 ml/kg/min combining to equal 7.00 ml/kg/min (ACSM et al., 2010). The first 3.50 ml/kg/min represents the metabolic cost of rest while the second 3.50 ml/kg/min represents the horizontal aspect of this exercise as the oxygen cost of unloaded cycling (ACSM et al., 2010; Lang et al.,1992; Latin & Berg, 1994; Londeree et al.,1997; Swain et al., 2000).

The first 3.50 ml/kg/min or one metabolic equivalent (MET) which represents the resting metabolic rate (RMR) is a widely used standard in the field of exercise physiology (Kwan, Woo, & Kwok, 2004). In recent research it has been observed that this value of 3.50 ml/kg/min significantly overestimates RMR (Byrne, Hills, Hunter, Weinsier, & Schutz, 2005; Kwan et al., 2004). To some extent this overestimation may help to explain why the y-intercept of the ACSM equation is significantly higher and outside of the range of the y-intercept for the OU equation.

The oxygen cost of unloaded cycling, that is the cost of the muscles contracting in order to move the legs in a cycling motion with no resistance, is the second component of the y-intercept in the ACSM equation (Sidossis, Horowitz, & Coyle, 1992). While this value of 3.50 ml/kg/min is simply added on to the ACSM prediction equation, in the founding equations that were used to develop the ACSM equation, this variable was multiplied by the cyclist's body weight in order to calculate the total, relative cost of unloaded cycling for each individual (ACSM et al., 2010; Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997).

Ergometer

The cost of unloaded cycling is also affected by the type of ergometer being used. The three founding equations' data were collected using a Monark cycle ergometer (Varberg, Sweden), while the OU equation was created using the "gold standard" Lode cycle ergometer (Lode BV Excalibur Sport 925900, Gronigen, Netherlands) (Earnest, Wharton, Church, & Lucia, 2005; Lang et al.,1992; Latin & Berg, 1994; Londeree et al., 1997). Paton and Hopkins (2001) discussed friction braked cycles, such as the Monark, commonly underestimated power output while electromagnetic braked cycles such as the Lode, commonly overestimated power output. This could have resulted in the participants in the three founding studies working harder than the WR that was entered into the regression analysis (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997). This discrepancy would elicit a higher VO_2 at each WR. While the relationship between the increase in VO_2 and an increase in WR (slope) does not change, the difference in WR must be represented in the y-intercept. In contrast, the participants in this research using the Lode cycle would be working at a slightly lower WR than was entered into the regression equation and, again, because the relationship between VO_2 and WR does not change, this difference is reflected by a lower y-intercept.

Cadence

In addition, cadence has been thought to impact the energy cost of cycling (Sidossis et al., 1992). Two of the three founding equations had their participants pedal at the set rate of 60 RPM, while the third study created three different equations with participants pedaling at 50, 70, and 90 RPM (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997). The cadence was not set for the participants in the present study; however the average submaximal cadence was 84.46 ± 8.94 and there was no significant difference between the average cadence of the first and second SXT. In a recent investigation, participants cycled at a set work rate with different pedal rates. It was found the cadence did not significantly contribute to the regression model for predicting

VO_2. This means that as long as the WR was the same, they observed no significant differences in VO_2 with a change in cadence (McDaniel, Durstine, Hand, & Martin, 2002). This gives justification to the fact that we did not control the cadence of our participants, and that this lack of control should not have affected the resulting VO_2.

Training status

The difference in the predicted values between the two equations may also be due to the fitness level of the participants used to create these equations. The participants in this study aerobically exercised at least 3 days a week and were familiar with cycling. Trained individuals often have an increased mechanical efficiency, because of a high representation of type one muscle fibers due to training (Hopker et al., 2007). The participants in this study would have lower relative VO_2 values at matching WR values than the participant pool of the three founding studies that ranged from sedentary to elite cyclist in one study, and no trained cyclists in the other two studies (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997).

Below and Above 200 Watts

Due to the limitation of the ACSM prediction equation, regarding it only being accurate up to 200 watts, it was important to determine whether or not the OU equation was acceptable at WR on both sides of this point (ACSM et al., 2010). When the variables were analyzed by regression there was no significant difference observed between the sorted variable coefficient or the interaction coefficient (see Table 3). This indicates that neither the slopes nor y-intercepts representing the relationship between relative VO_2 and WR on either side of 200 watts were different from one another. This further demonstrates one equation will fit WR both below and above 200 watts. This is beneficial to the aerobically trained population by allowing them to use the same equation at WR between 109 and 425 watts.

Below and Above Ventilatory Threshold

Ventilatory threshold is identified as the point of exercise where there is a distinct increase in VCO_2 without a matching distinct increase in VO_2. The distinct increase in CO_2 is due to CO_2 being produced as a byproduct of buffering H^+; this is why VO_2 does not increase at the same rate as VCO_2 at this point of exercise (Hopker et al., 2011). The slow component of VO_2 that is present after VT is reflected by a nonlinear increase in VO_2 with an increase in WR (Hopker, et al., 2011). This can be observed as a change in slope, with the slope increasing in untrained individuals and decreasing to a small extent in trained individuals (Lucia et al., 2002).

To investigate if this relationship existed in our sample, the data were sorted by being above or below an individual's VT. When the sorted variable along with WR/BW and the interaction were analyzed with relative VO_2 by regression, neither the code nor interaction coefficients were significant (see Table 4). Again this means that if the data were split and created into two separate linear equations, the slope of these lines and their y-intercepts would not be significantly different from one another. Considering the individuals used to create the OU equation were aerobic athletes, this confirms the idea that there is little change in the slope of the relationship of VO_2 and WR after VT in trained individuals (Gaesser, 1994; Xu & Rhodes, 1999). This is beneficial to aerobic athletes because no matter their WR, above or below their VT, they can still use the OU equation.

Application

While it is common for cyclists, especially elite competitive cyclists, to go into laboratory facilities and use stationary ergometers to be physiologically tested, not many train, and fewer race, in the laboratory facility on these ergometers. Many cyclists have power meters installed on their bikes, so even when they are not in the lab, they can determine their power output values and then calculate their VO_2 and caloric expenditure (Reiser, Meyer, Kindermann, & Daugs, 2000). Even though power meters have been validated for their accuracy and reliability to the Lode cycle ergometer, there are environmental factors that are not present in the lab that put additional physiological stresses on the body (e.g., heat, wind resistance; other riders) that may increase the VO_2 of an individual while working at a set rate (Reiser et al., 2000).

Limitations

The major limitation of the OU equation is that it was created using the data from only 1 woman out of 29 participants. Even though 19 females, who averaged over 4½ hours of aerobic activity per week participated in the GXT, only 1 qualified with a WR > 300 watts.

A second limitation to this research was that the cadence was not set as it was in the research that was conducted to create the current version of the ACSM prediction equation (Lang et al., 1992; Latin & Berg, 1994; Londeree et al., 1997). Setting a standard cadence could decrease the variability of the cost of unloaded cycling. However, to make the OU equation more applicable to a cyclist's actual training, collecting data from a range of cadences would be more specific.

The OU equation is also limited to the aerobically trained population. The variables of resting metabolic rate, the cost of unloaded cycling, and the slope of the relationship between VO_2 and WR may be different in the trained population compared to the untrained; therefore, this could result in the OU equation not being accurate in an untrained population.

Future Research

Future research should validate the OU equation. The calculation of R_c^2 was used in the current study to cross validate and determine how much shrinkage would occur in a separate sample. Other methods should be used as well to validate this equation in the aerobic population, for both males and females, as well as for the general population. More data needs to be collected from aerobically trained females. The minimum qualifying WR of this study was too high for even some well-trained female athletes. Setting the qualifying WR for females at 250 watts would have resulted in 8 (out of 19) qualified to participate in this study.

The WR range could be expanded to include WR lower than 109 watts and possibly WR higher than 425 watts. To go above the top end of the range collected in this study, cyclists who could achieve WRmax of at least 475 watts would need to be recruited and analyzed. Collecting data outside of the range used in this research would expand the applicability of the equation.

Equations could be created using different cycle ergometers or power meters. Even though the Lode cycle ergometer is the “gold standard” they are expensive and may not be in every exercise laboratory. Also different ergometers or the cyclists’ different bikes could have pedal arms of different lengths, although this difference in lengths has been shown to have little effect on the cost of cycling (McDaniel et al., 2002). Using regression analysis to create an equation for aerobically trained individuals on the Monark cycle or power meters would allow laboratories who do not have Lode cycle ergometers accurately predict VO_2.

REFERENCES

Algina, J., & Keselman, H. J. (2000). Cross-validation sample sizes. *Applied Psychological Measurement, 24*, 173-179.

American College of Sports Medicine. (1975). *Guidelines for graded exercise testing and exercise prescription*. Philadelphia, PA: Lea & Febiger.

American College of Sports Medicine. (1980). *Guidelines for graded exercise testing and exercise prescription* (2nd ed.). Philadelphia, PA: Lea & Febiger.

American College of Sports Medicine. (1986). *Guidelines for exercise testing and prescription* (3rd ed.). Philadelphia, PA: Lea & Febiger.

American College of Sports Medicine (Ed.). (2010). *ACSM's resource manual for guidelines for exercise testing and prescription* (6th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

American College of Sports Medicine, Franklin, B. A., Whaley, M. H., & Howley, E.T. (Eds). (2000). *ACSM's guidelines for exercise testing and prescription* (6th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

American College of Sports Medicine, Kenny, W. L., Humphrey, R. H., Bryant, C. X., Mahler, D. A., Froelicher, V. F., . . . York, T. D. (Eds.). (1995). *ACSM's guidelines for exercise testing and prescription* (5th ed.). Philadelphia, PA: Williams & Wilkins.

American College of Sports Medicine, Stoedefalk, K. G., Faulkner, J. A., Fox, M. S., Miller, Jr., H. S., Balke, B., . . . Wolfe, L. A. (Eds.). (1991). *Guidelines for exercise testing and prescription* (4th ed.). Philadelphia, PA: Lea & Febiger.

American College of Sports Medicine, Thompson, W. R., Gordon, N. F., & Pescatello, L. S. (Eds.). (2010). *ACSM's guidelines for exercise testing and prescription* (8th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

American College of Sports Medicine, Whaley, M. H., Brubaker, P. H., & Otto, R., M. (Eds.). (2006). *ACSM's guidelines for exercise testing and prescription* (6th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

Aron, A., Aron, E. N., & Coups, E. J. (2005). *Statistics for the behavioral and social sciences* (3rd ed.). Upper Saddle River, NJ: Pearson Education.

Astrand, P. O., & Ryhming, I. (1954). A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *Journal of Applied Physiology, 7*(2), 218-221.

Beam, W. C., & Adams, G. M. (2011). *Exercise physiology laboratory manual* (6th ed.). New York, NY: McGraw-Hill.

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

Byrne, N. M., Hills, A. P., Hunter, G. R., Weinsier, R. L., & Schutz, Y. (2005). Metabolic equivalent: One size does not fit all. *Journal of Applied Physiology, 99*(3), 1112-1119. doi:10.1152/japplphysiol.00023.2004

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Coyle, E. F. (1999). Physiological determinants of endurance exercise performance. *Journal of Science and Medicine in Sport, 2*(3), 181-189.

Crouter, S. E., Antczak, A., Hudak, J. R., Della Valle, D. M., & Haas, J. D. (2006). Accuracy and reliability of the ParvoMedics TrueOne 2400 and MedGraphics VO2000 metabolic systems. *European Journal of Applied Physiology, 98*(2), 139-151. doi:10.1007/s00421-006-0255-0

Dalleck, L. C., Kravitz, L., & Robergs, R. A. (2006). Development of a submaximal test to predict elliptical cross-trainer VO2max. *Journal of Strength and Conditioning Research, 20*(2), 278-283. doi:10.1519/R-17014.1

Earnest, C. P., Wharton, R. P., Church, T. S., & Lucia, A. (2005). Reliability of the lode excalibur sport ergometer and applicability to computrainer electromagnetically braked cycling training device. *Journal of Strength and Conditioning Research, 19*(2), 344-348. doi:10.1519/R-15714.1

Faria, E. W., Parker, D. L., & Faria, I. E. (2005). The science of cycling: Physiology and training—Part 1. *Sports Medicine, 35*(4), 285-312.

Ferrannini, E. (1988). The theoretical bases of indirect calorimetry: A review. *Metabolism: Clinical and Experimental, 37*(3), 287-301.

Gaesser, G. A. (1994). Influence of endurance training and catecholamines on exercise VO2 response. *Medicine and Science in Sports and Exercise, 26*(11), 1341-1346.

Haugen, H. A., Chan, L. N., & Li, F. (2007). Indirect calorimetry: A practical guide for clinicians. *Nutrition in Clinical Practice, 22*(4), 377-388.

Hawley, J. A., & Noakes, T. D. (1992). Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. *European Journal of Applied Physiology and Occupational Physiology, 65*(1), 79-83.

Hochachka, P. W. (1985). Fuels and pathways as designed systems for support of muscle work. *The Journal of Experimental Biology, 115*, 149-164.

Hopker, J. G., Coleman, D. A., & Wiles, J. D. (2007). Differences in efficiency between trained and recreational cyclists. *Physiologie Appliquee, Nutrition Et Metabolisme [Applied Physiology, Nutrition, and Metabolism], 32*(6), 1036-1042. doi:10.1139/H07-070

Hopker, J. G., Jobson, S. A., & Pandit, J. J. (2011). Controversies in the physiological basis of the 'anaerobic threshold' and their implications for clinical cardiopulmonary exercise testing. *Anesthesia, 66*(2), 111-123. doi:10.1111/j.1365-2044.2010.06604.x

Howley, E. T., Bassett, D. R., Jr, & Welch, H. G. (1995). Criteria for maximal oxygen uptake: Review and commentary. *Medicine and Science in Sports and Exercise, 27*(9), 1292-1301.

Jequier, E., & Felber, J. P. (1987). Indirect calorimetry. *Bailliere's Clinical Endocrinology and Metabolism, 1*(4), 911-935.

Kemi, O. J., & Wisloff, U. (2010). High-intensity aerobic exercise training improves the heart in health and disease. *Journal of Cardiopulmonary Rehabilitation and Prevention, 30*(1), 2-11. doi:10.1097/HCR.0b013e3181c56b89

Kwan, M., Woo, J., & Kwok, T. (2004). The standard oxygen consumption value equivalent to one metabolic equivalent (3.5 ml/min/kg) is not appropriate for elderly people. *International Journal of Food Sciences and Nutrition, 55*(3), 179-182. doi:10.1080/09637480410001725201

Lang, P. B., Latin, R. W., Berg, K. E., & Mellion, M. B. (1992). The accuracy of the ACSM cycle ergometry equation. *Medicine and Science in Sports and Exercise, 24*(2), 272-276.

Latin, R. W., & Berg, K. E. (1994). The accuracy of the ACSM and a new cycle ergometry equation for young women. *Medicine and Science in Sports and Exercise, 26*(5), 642-646.

Latin, R. W., Berg, K., Kissinger, K., Sinnett, A., & Parks, L. (2001). The accuracy of the ACSM stair-stepping equation. *Medicine and Science in Sports and Exercise, 33*(10), 1785-1788.

Latin, R. W., Berg, K. E., Smith, P., Tolle, R., & Woodby-Brown, S. (1993). Validation of a cycle ergometry equation for predicting steady-rate VO2. *Medicine and Science in Sports and Exercise, 25*(8), 970-974.

Levine, J. A. (2005). Measurement of energy expenditure. *Public Health Nutrition, 8*(7A), 1123-1132.

Londeree, B. R., Moffitt-Gerstenberger, J., Padfield, J. A., & Lottmann, D. (1997). Oxygen consumption of cycle ergometry is nonlinearly related to work rate and pedal rate. *Medicine and Science in Sports and Exercise, 29*(6), 775-780.

Lucia, A., Hoyos, J., & Chicharro, J. L. (2000). The slow component of VO2 in professional cyclists. *British Journal of Sports Medicine 34*(5), 367-374.

Lucia, A., Hoyos, J., Santalla, A., Perez, M., & Chicharro, J. L. (2002). Kinetics of VO(2) in professional cyclists. *Medicine and Science in Sports and Exercise, 34*(2), 320-325.

Lucia, A., Rivero, J. L., Perez, M., Serrano, A. L., Calbet, J. A., Santalla, A., & Chicharro, J. L. (2002). Determinants of VO(2) kinetics at high power outputs during a ramp exercise protocol. *Medicine and Science in Sports and Exercise, 34*(2), 326-331.

Maeder, M. T., Muenzer, T., Rickli, H., Brunner-La Rocca, H. P., Myers, J., & Ammann, P. (2008). How accurately are maximal metabolic equivalents estimated based on the treadmill workload in healthy people and asymptomatic subjects with cardiovascular risk factors? *International Journal of Sports Medicine, 29*(8), 658-663. doi:10.1055/s-2007-989319

Martins-Pinge, M. C. (2011). Cardiovascular and autonomic modulation by the central nervous system after aerobic exercise training. *Revista Brasileira De Pesquisas Medicas e Biologicas [Brazilian Journal of Medical and Biological Research], 44*(9), 848-854.

Matarazzo, J. D., Weiss, S. M., Herd, J. A., Miller, N. E., & Weiss, S. M. (Eds.) (1984). *Behavioral health: A handbook of health enhancement and disease prevention.* New York, NY: John Wiley & Sons.

Matarese, L. E. (1997). Indirect calorimetry: Technical aspects. *Journal of the American Dietetic Association, 97*(10 Suppl 2), S154-160.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology: Nutrition, energy, and human performance* (7th ed.). Baltimore, MD: Lippincott Williams & Wilkins.

McDaniel, J., Durstine, J. L., Hand, G. A., & Martin, J. C. (2002). Determinants of metabolic cost during submaximal cycling. *Journal of Applied Physiology, 93*(3), 823-828. doi:10.1152/japplphysiol.00982.2001

Mookerjee, S., Surmacz, C., Till, M., & Weller, B. (2005). Validation of an equation for predicting energy cost of arm ergometry in women. *European Journal of Applied Physiology, 95*(2-3), 115-120. doi:10.1007/s00421-005-1397-1

Neder, J. A., Nery, L. E., Silva, A. C., Andreoni, S., & Whipp, B. J. (1999). Maximal aerobic power and leg muscle mass and strength related to age in non-athletic males and females. *European Journal of Applied Physiology and Occupational Physiology, 79*(6), 522-530.

Olson, M. S., Williford, H. N., Blessing, D. L., Wilson, G. D., & Halpin, G. (1995). A test to estimate VO2max in females using aerobic dance, heart rate, BMI, and age. *The Journal of Sports Medicine and Physical Fitness, 35*(3), 159-168.

Paton, C. D., & Hopkins, W. G. (2001). Tests of cycling performance. *Sports Medicine, 31*(7), 489-496.

Perot, C., Goubel, F., & Mora, I. (1991). Quantification of T- and H-responses before and after a period of endurance training. *European Journal of Applied Physiology and Occupational Physiology, 63*(5), 368-375.

Reiser, M., Meyer, T., Kindermann, W., & Daugs, R. (2000). Transferability of workload measurements between three different types of ergometer. *European Journal of Applied Physiology, 82*(3), 245-249. doi:10.1007/s004210050678

Ross, R. M., Murthy, J. N., Wollak, I. D., & Jackson, A. S. (2010). The six minute walk test accurately estimates mean peak oxygen uptake. *BMC Pulmonary Medicine, 31*(10). doi:10.1186/1471-2466-10-31

Ruiz, A., & Sherman, N. (1999). An evaluation of the accuracy of the American College of Sports Medicine metabolic equation for estimating the oxygen cost of running. *Journal of Strength and Conditioning Research, 13*(3), 219-223. doi:10.1519/1533-4287(1999)013<0219:AEOTAO>2.0.CO;2

Saarni, S. E., Rissanen, A., Sarna, S., Koskenvuo, M., & Kaprio, J. (2006). Weight cycling of athletes and subsequent weight gain in middleage. *International Journal of Obesity*, *30*(11), 1639-1644.

Schoeller, D. A. (2007). Making indirect calorimetry a gold standard for predicting energy requirements for institutionalized patients. *Journal of the American Dietetic Association, 107*(3), 390-392. doi:10.1016/j.jada.2007.01.030

Sidossis, L. S., Horowitz, J. F., & Coyle, E. F. (1992). Load and velocity of contraction influence gross and delta mechanical efficiency. *International Journal of Sports Medicine, 13*(5), 407-411. doi:10.1055/s-2007-1021289

Stevens, J. P. (2007). *Intermediate statistics: A moderate approach* (3rd ed.). New York, NY: Lawrence Erlbaum Associates.

Swain, D. P. (2000). Energy cost calculations for exercise prescription: An update. *Sports Medicine, 30*(1), 17-22.

Wasserman, K., Hansen, J. E., Sue, D. Y., Casaburi, R., & Whipp, B. J. (1999). *Principles of exercise testing and interpretation, including pathophysiology and clinical applications* (3rd ed.). Baltimore, MD: Lippincott, Williams & Wilkins.

Wilmore, J. H., & Costill, D. L. (1973). Adequacy of the haldane transformation in the computation of exercise VO2 in man. *Journal of Applied Physiology, 35*(1), 85-89.

Xu, F., & Rhodes, E. C. (1999). Oxygen uptake kinetics during exercise. *Sports Medicine, 27*(5), 313-327.

Zavorsky, G. S. (2000). Evidence and possible mechanisms of altered maximum heart rate with endurance training and tapering. *Sports Medicine, 29*(1), 13-26.

APPENDIX A: RECRUITMENT POSTER

OU: EXERCISE PHYSIOLOGY LAB

PARTICIPANTS

NEEDED

Participants are needed for a study measuring the oxygen consumption (VO_2) and power outputs of aerobically trained individuals exercising on a stationary cycle ergometer.

Eligible Participants:

Males & Females 18-55 years

(46-55 years w/clearance from physician)

Currently Exercise at least 3 days per week

No Known:

- Cardiovascular, uncontrolled or untreated Metabolic or Pulmonary Diseases
- Orthopedic Conditions that Limit Cycling Ability

Testing will only require a maximum of 3 hours of participant's time over three different days. Participants will be provided with physiological results from all completed tests.

Participants will be asked to refrain from exercise and physical activity above typical daily routine, alcohol, nicotine, caffeine and nutritional supplements for 12 hours and be fasted for 4 hours before participation.

Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu
Anna Gray ag188806@ohio.edu

APPENDIX B: INFORMED CONSENT DOCUMENT

Ohio University Consent Form

Title of Research: **Creation of a Modified Equation to Predict VO_2 at on a Cycle Ergometer**

Researchers: **Anna R. Gray**, Exercise Physiology Graduate Student and **Michael R. Kushnick**, Ph.D. Associate Professor of Exercise Physiology

You are being asked to participate in a research project. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

EXPLANATION OF STUDY

This study is being conducted because the current equation to predict oxygen consumption (VO_2) of cycling activities is only accurate at work rates at and below 200 watts. A watt is a unit of the measurement of power. Many individuals who are aerobically trained can easily cycle at rates above 200 watts, but because of the restriction of the current equation, the VO2 cost of this cycling cannot be accurately estimated.The **purpose** of this study is to develop a new equation to predict VO_2 at work rates above 200 watts.
Participants will be asked to complete both maximal and submaximal graded exercise tests. During the maximal graded exercise test you will work to your maximum capacity (up to 100%). This will involve exercise that starts out light (35-40%) then progresses to a moderate (41-60%), to hard (61-80%), to very hard intensity (81-99%) and end with a maximal (100%) effort; each stage lasting for a few minutes. During the submaximal exercise trials the exercise will progress from light (35-40%) to moderate (41-60%) to hard (61-80%), and be no more than a very hard intensity (81-90%); each lasting for a few minutes."

You will be asked to participate in the informed consent process (including reading and acknowledging the details and methods used in this study). In addition you will complete a health history and exercise questionnaire. For inclusion into the study you must be a man or woman age 18-55 years of age familiar with bicycle exercise, exercise aerobically at least 3 days per week, are not pregnant, have no know cardiovascular diseases and no uncontrolled or untreated pulmonary or metabolic diseases, and not have been ill one week prior to the initial visit. If you are over the age of 45 you must have permission from your physician to participate. This session will take approximately 20 minutes.

If you meet these requirements and you identify that you routinely exercise(at least 3 days per week) you will be asked to complete an additional test to determine eligibility.

Upon arrival for the initial and subsequent exercise testing sessions you will be asked to be fasted for four hours and have refrained from caffeine, alcohol, nicotine, nutritional supplements and exercise and physical activity above your normal daily routine for 12 hours.

Maximal Bicycle Graded Exercise Test (VO_2max)

For the next screening test, you will be asked to complete a maximal cycle graded exercise test to determine VO_2max and maximal power output (highest power output, product of resistance and revolutions per minute, measured in watts)according to standard procedures employed in the Exercise Physiology Laboratory at Ohio University. You will wear a mouthpiece held in place by headgear so that ventilatory measurements may be made throughout the test (oxygen consumption, carbon dioxide production, ventilation and respiratory exchange ratio) by a metabolic measurement cart (ParvoMedics, Inc.). The mouthpiece is rubber and fits inside of your mouth, between your teeth with your lips covering the outside. You will also be wearing a nose clip which will insure that you are breathing only through your mouth so that all of the air you expire will be collected. In addition, your heart rate will be monitored continuously by a heart rate monitor chest strap and coordinated watch that you will be wearing throughout the warm-up, test and during the recovery periods.

This test will consist of 1-3 minute stages, with the first few stages at low intensity (warm-up) and will increase in intensity each stage until you can no longer maintain a minimum revolution per minute or the tester determines your respiratory variables do not increase with three subsequent workloads. This test will take approximately 8-30 minutes and your commitment for this day will be approximately 30-45 minutes.

Communication between you and the tester will occur throughout the test and will enable feedback on perceived exertion; example, "Are you able to continue?" A visible "Thumbs up" will equal a "Yes", "Thumbs down" will equal a "No", a teetering of the hand will equal "I don't know" and an "X" over the chest will mean "I must stop immediately."You should feel free to signal the researchers in this way at any time throughout the testing to indicate that you either want to stop or continue the testing.

If your maximal power output is greater than 300 watts as determined by this test you fully qualify for this study and will be asked to return for two more submaximal exercise trials.

Submaximal Exercise Trials

If you are a qualified participant, you will be asked to complete two subsequent submaximal trials in random order. The submaximal trials will consist of exercise while your ventilatory data is collected through the mouth piece.The mouthpiece will be worn throughout the stages and may be removed during the three rest periods. (as described above for the maximal bicycle graded exercise test). This will consist of six stages each of increasing intensity up to 85 or 90% of your predetermined maximal watts – the first two will serve as warmup (i.e. 40 and 50% for trial 1 and 35 and 45% for trial 2). Each stage will last between 5-10 minutes and between each stage a low intensity active recovery period will be provided for up to 3 minutes. Therefore, the total time on the cycle for each trial will be between 45 and 75 minutes.

On the day of trial one you will have skin folds taken at select sites according to standard procedures. These skin folds will be used to predict percent body fat and will be used for descriptive purposes only. On women these sites include the back of upper arm (triceps), hip (suprailliac crest) and mid-thigh and for men these include the chest (pectoralis), abdomen (umbilicus) and mid-thigh for the men. Pinches of the skin (cutaneous membrane) and the sub-skin (subcutaneous) fat will be held for approximately five seconds while subsequent measurements with a hand-held caliper occur. Pinches will take place in a rotating fashion with three to five times per site, allowing at least one minute between each pinch. This procedure will take approximately 5 minutes.

All three sessions (maximal test and two submaximal exercise trials) will be performed at approximately the same time of day and no less than two, but no more than ten days apart. Furthermore, you will have to refrain from each of the following prior to each exercise testing session: consumption of food or beverages other than water for 4 hours; use of products containing nicotine, caffeine, alcohol or nutritional supplements for 12 hours; and, participation in exercise or physical activity above your typical daily routine for 12 hours.

Your total commitment for this project, if qualified for and choose to complete the maximal and two submaximal tests, will last between 2 ½ to 4 hours total over a period lasting no longer than22 days. If you complete the maximal graded exercise test and are not qualified or choose not to complete either of the submaximal tests your time commitment will be slightly over one hour.

Risks and Discomforts

All procedures have been designed and will be implemented in order to minimize the potential risks to human subjects. The age range of the subject population has been selected to conform to the American College of Sports Medicine's recommendations regarding maximal exercise testing and this protocol is seeking only individuals familiar with bicycle exercise. Moreover, the procedure for the maximal test to elicit maximal aerobic capacity and power output is a standard practice in this field and our laboratory. Furthermore, the individual ventilatory responses to exercise will be determined and provide each subject with an indication of current health and physiological performance. According to the American College of Sports Medicine, the risks of injury to apparently healthy individuals during this type of test are low. Even though the risks associated with exercise and maximal exercise are low there is a possibility that you may sprain/strain muscles, have a cardiovascular event (including a heart attack), and have discomfort associated with cycling.

Nonetheless, all investigators follow the Exercise Physiology Laboratory safety procedures. This includes that all individuals involved in research will be: 1) American Red Cross (or similar) CPR/First Aid/AED certified; 2) aware of the location and proper use of the laboratory's AED; 3) know the location and emergency phone numbers. All reusable equipment coming in contact with the skin, saliva and/or sweat will be properly cleaned and disinfected prior to re-use as per manufacturers specifications. Specifically, the mouthpieces, breathing carriages, valves and nose clips will be disinfected. Plastic headgear and heart rate monitoring equipment will be cleansed following each use. Plastic hoses will be rinsed with tap water and allowed to dry prior to re-use.

Furthermore, you will be aware of the purpose and procedure for each test that you will perform before it begins and will be made aware of what is expected of you throughout this study. You are encouraged to ask question during the testing and/or to contact the researchers at any time during the course of this investigation with questions, comments, or concerns.

You should be aware that you are under no commitment to continue and that your participation in this study is completely voluntary.

If you experience any adverse effects that require immediate medical attention, please contact your personal physician or go an emergency room, and then please convey this information later to Anna Gray or Dr. Michael Kushnick. If you have any further questions throughout the study please contact: Anna R. Gray or Dr. Michael R. Kushnick (contact information below).

Benefits

You will gain knowledge about your health and fitness and gain experience in the Exercise Physiology Laboratory and with the equipment and procedures utilized in this study. The benefits of this investigation to society include the knowledge gained by developing an equation to predict oxygen consumption above 200 watts.

Confidentiality and Records

All data will be kept in the researcher's office in a locked file. You will receive a subject number and only the investigator will be able to identify your records. A code key will be developed to match your name you're your subject number and data. The data will be compiled and analyzed with only group data being used for dissemination. After the data is compiled and the subjects are provided with their individual results the master list will be destroyed

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:
* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

Compensation
No compensation will be given to participants.

Contact Information

If you have any questions regarding this study, please contact: Anna R. Gray via e-mail ag188806@ohio.eduor phone (740)412-9127 -or- Dr. Michael R. Kushnick via e-mail kushnick@ohio.edu or phone (740)593-0496.
If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are between 18 and 55 years of age, and if over 45 have clearance from your physician
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature____ Date______________

Printed Name____ Version Date: [*3/4/12]*