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Prediction of Cardiorespiratory Fitness from Maximal Anaerobic Capacity

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PREDICTION OF CARDIORESPIRATIRY FITNESS FROM MAXIMAL ANAEROBIC CAPACITY

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ABSTRACT

Prediction of Cardiorespiratory Fitness from Maximal Anaerobic Capacity

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Incremental treadmill VO_2max protocols are often considered the superior method of assessing cardiorespiratory fitness. These exercise test protocols stress aerobic energy production pathways. However, at the point of VO_2max attainment anaerobic energy systems are the predominant mechanisms of adenosine triphosphate (ATP) production. Likewise, the Wingate cycle test, a commonly accepted method of anaerobic capacity assessment stresses anaerobic energy pathways. Based on the utilization of energy production pathways at the point of VO_2max and maximal anaerobic capacity attainment a relationship between VO_2max and Wingate exercise test protocols may exist. This potential relationship may facilitate the prediction of cardiorespiratory fitness from maximal anaerobic capacity assessed by an incremental treadmill VO_2max test and Wingate cycle test respectively. The purpose of this study is to develop prediction equations (gender-independent, gender specific) that predict maximal aerobic capacity using anaerobic power measurements (peak power, mean power, fatigue index) obtained during a 30 second Wingate cycle test as the primary predictor variables along with demographics (sex, age), anthropometrics (height, weight, body fat, seven site skinfolds, thigh girth, hip girth) and resting heart rate as secondary predictor variables. Participants (N=72) completed an incremental treadmill VO_2max protocol followed by a Wingate cycle test separated by a 15-20 minute rest period. Eight participants failed to satisfy true VO_2max attainment criteria, therefore 64 participants were included in statistical analysis (men n=32; women n=32). Multiple linear regression analysis was used to develop gender-independent and gender specific cardiorespiratory fitness prediction models. Standard error of estimate (SEE) and percent of standard error of estimate (SEE%) were used to assess model accuracy. Predicted residual sum of squares (PRESS) statistics were used to assess model stability. Significance was accepted at the $p \leq 0.05$ level. For the gender-independent prediction model sex, height, weight, triceps skinfold, thigh skinfold, body fat, thigh girth, hip girth, resting heart rate (RHR), peak power (PP), mean power (MP), and fatigue index (FI) were significantly correlated to VO_2max (r= -0.79, p<0.001; r=0.74, p<0.001; r=0.74, p<0.001; r= -0.53, p=<0.001; r= -0.56, p<0.001; r= -0.60, p<0.001; r=0.42, p=0.001; r=0.35, p=0.005; r= -0.28; p=0.023; r=0.78, p<0.001; r=0.77, p<0.001; r=0.36, p=0.004) respectively. However, peak power (PP), weight, body fat, and RHR were the only significant contributors to the model (p<0.05) producing the following prediction model: $\hat{Y} = 2.627 + (0.001\times PP) + (0.037\times weight) + (-5.315\times body\ fat) + (-0.019\times RHR)$. This model was determined to be accurate (SEE= 0.37; SEE%=10.89) and stable ($R^2 = 0.841$ vs. $R^2_{PRESS} = 0.782$; SEE = 0.37 vs. $SEE_{PRESS} = 0.41$). For the male specific model height, weight, thigh girth, PP, MP, and FI were significantly correlated to VO_2max (r=0.39, p=0.029; r=0.36, p=0.04; r=0.41, p=0.021; r=0.62, p<0.001; r=0.61, p<0.001; r=0.36, p=0.045) respectively. PP was the only significant contributor to the model revealing the following model: $\hat{Y} = 2758 + (0.002\times PP)$. This model is slightly less accurate than the gender-independent model (SEE=0.49; SEE%=11.98) but not stable ($R^2 = 0.380$ vs. $R^2_{PRESS} = -0.041$; SEE = 0.49 vs. $SEE_{PRESS} = 0.61$). For the female specific model height, weight, thigh girth, RHR, and MP were significantly correlated to VO_2max (r=0.57, p=0.001; r=0.60, p<0.001; r=0.49, p=0.004; r= -0.48, p=0.006;

r=0.37; p=0.029) respectively. To maintain an anaerobic power measurement, MP was the only predictor maintained in the model producing a simple linear regression model ($\hat{Y} = 2.061 + 0.002 \times MP$). This model is the least accurate (SEE=0.45; SEE%=16.78) and unstable ($R^2 = 0.149$ vs. $R^2_{PRESS} = 0.018$; SEE = 0.45 vs. $SEE_{PRESS} = 0.50$). The results of this study indicate the gender-independent model can be generalized to an independent sample of highly active college aged adults. The gender specific models predict VO_2max to a similar degree of accuracy to the gender-independent model however, these models are not stable. Therefore, the application of the gender specific models to independent samples of highly active college aged men and women is cautioned.

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CHAPTER 1

INTRODUCTION

The premise of exercise testing in the field of exercise physiology is to stress the energy production pathway responsible for producing adenosine triphosphate (ATP) for the completion of the task. Two such collections of exercise testing include those which evaluate maximal aerobic capacity and maximal anaerobic capacity. Maximal aerobic capacity or maximal oxygen consumption (VO_2max) represents the maximum rate the body can take in, transport, and utilize oxygen during exercise (Powers & Howley, 2009; Akalan, Kravitz, & Robergs, 2004). The most common laboratory method to determine VO_2max is by direct measurement through a gas analysis system. According to the American College of Sports Medicine, VO_2max is an accepted method of measuring cardiorespiratory fitness and is often accepted as the superior method of assessment (Akalan et al., 2004; Howley, Basset, & Welch, 1995). In the early 1920s, exercise physiologists discovered the point of VO_2max attainment and attributed this phenomena to the physiological limitations of the cardiorespiratory system (Hill & Lupton, 1923). Due to the connection between VO_2max and cardiorespiratory fitness, VO_2max testing has become the primary method for assessing cardiorespiratory fitness in athletes and individuals with cardiovascular conditions (Akalan et al., 2004). The incremental VO_2max protocol is widely considered superior at eliciting a VO_2max by increasing workrate by either increasing speed, incline, or both on a treadmill at a predetermined time interval. In order to reach VO_2max an individual must run until exhaustion or until they can no longer continue the desired power output (Powers & Howley, 2009). Studies have shown that a treadmill protocol lasting 8-12 minutes yields the highest VO_2max values (Powers & Howley, 2009; Akalan et al., 2004). Based on this time frame and incremental nature of the protocol all energy production pathways are utilized during the course of the test. As the incremental protocol increases intensity until exhaustion, energy production pathways switch from primarily aerobic to anaerobic at the "crossover point". These anaerobic energy production pathways continue to predominate until VO_2max is attained (Powers & Howley, 2009).

Assessment of anaerobic capacity can be executed through a variety of laboratory and field modalities. The Wingate cycle test is considered the superior testing method to obtain anaerobic power measures (Patton & Duggan, 1985). This supramaximal exercise protocol produces peak power, mean power, and fatigue index over 30 seconds of cycle pedaling against resistance (Powers & Howley, 2009; Patton, Murphy, & Frederick, 1984). The purpose of the Wingate cycle test is to perform as many pedal revolutions in 30 seconds with a predetermined resistance, 7.5% body weight, applied to the flywheel (Patton et al, 1984; Patton & Duggan, 1985; Powers & Howley, 2009). The assessment of anaerobic capacity through the Wingate cycle test is used to evaluate the capacity of anaerobic energy pathways to produce ATP required to complete the test. Similar to a VO_2max test, the Wingate cycle test uses more than one energy production pathway. During the first portion of the test the phosphagen (ATP-PC) system is engaged to produce ATP for the working muscle tissue. The second portion of energy production is provided by a combination of energy production pathways lasting the duration of the test (Powers & Howley, 2009). Based on the energy systems being utilized at the point of VO_2max attainment and during a Wingate cycle test it becomes apparent that results from these two assessments may be related. This potential relationship may facilitate the prediction of VO_2max values from Wingate cycle test results.

There has been very little research attempting to connect the anaerobic portion of a maximal aerobic capacity test to an anaerobic capacity measurement and only two previous studies have investigated this potential relationship. Jones and McCartney (1986) focused on the impact of anaerobic power on aerobic performance and developed a prediction equation for VO_2max performance from 30s anaerobic cycle results. However, the population utilized to develop this prediction equation was comprised of sedentary individuals and utilized a cycle protocol to assess VO_2max rather than a treadmill protocol (Jones & McCartney, 1986). A similar study was conducted to determine a relationship between peak power output and VO_2max through anaerobic and aerobic cycle protocols in trained cyclists. The results indicate that peak power and VO_2max are highly correlated, therefore in this population peak power output can accurately predict VO_2max (Hawley & Noakes, 1992). To date no other research has attempted to predict VO_2max obtained through a treadmill protocol from anaerobic power in healthy adults, which is the goal of the current study.

Purpose

The purpose of this study is to develop a prediction equation which will predict maximal aerobic capacity using anaerobic power measurements (peak power, mean power, fatigue index) obtained during a 30 second Wingate cycle test as the primary predictor variables along with demographics (sex, age), anthropometrics (height, weight, body fat, seven site skinfolds, thigh girth, hip girth) and resting heart rate as secondary predictor variables..

Research Hypothesis

It is hypothesized that anaerobic capacity measures (peak power, mean power, and fatigue index) achieved during a Wingate cycle test in combination with demographics, various body composition measures, and/or resting heart rate will accurately predict maximal aerobic capacity (VO_2max) obtained during an incremental treadmill protocol.

Significance

To date no research has attempted to predict VO_2max obtained through a treadmill protocol from anaerobic power obtained through a 30s Wingate cycle protocol in healthy adults. The importance of developing this equation is to accurately predict maximal aerobic capacity values in a short amount of time. This is advantageous when standard maximal aerobic testing requiring 6-12 minutes in addition to time spent preparing the equipment can be reduced to 30 seconds of data collection. For example, testing large groups of athletes or research participants becomes more efficient when total time for each individual lasts a few minutes compared to 6-12 minutes. This predictive method would also provide researchers, coaches and athletes both aerobic and anaerobic physiological results compared to a variety of other predictive methods which provide results for only one type of test. Additionally, these values could be used for training monitoring along with distinguishing potential limitations which may require further development through training. Athletes and recreationally active individuals may also use this predictive method as a quick monitoring tool during a training season to gauge improvements or decrements throughout the season without completing a full maximal exercise test. Although treadmill maximal aerobic capacity tests are considered the superior method of measuring maximal aerobic capacity, various populations may not have access to the equipment needed to directly measure maximal oxygen consumption. However, these individuals may have access to a cycle ergometer that allows the application of a weighted resistance instantaneously to the flywheel. This equation would allow these individuals to predict their VO_2max when a direct measurement is not feasible. Finally, this method may be applied to special populations, most notably individuals with upper extremity limitations which could inhibit participation in a maximal treadmill test. A predictive equation for maximal aerobic capacity from maximal anaerobic capacity will fill a gap in the current research on maximal and predictive exercise test methods while providing an additional predictive method for those that are unable to complete maximal testing and situations in which maximal testing is not physically or economically possible.

CHAPTER 2

LITERATURE REVIEW

The majority of exercise capacity testing aims to directly measure physiological responses to various exercise stimuli including maximal aerobic and anaerobic testing. The purpose of these tests is to stress the primary energy system utilized in order to complete the task. The results of these tests allow practitioners to classify clients in terms of aerobic and anaerobic fitness compared to normative values. However, there are circumstances in which maximal exercise testing may be contraindicated such as chronic or acute disease conditions (Powers & Howley, 2009). The need to classify these individuals propelled the development of a variety of submaximal and predictive exercise protocols for aerobic capacity. Conversely, the development of submaximal and predictive protocols for anaerobic capacity testing is virtually non-existent. Although this area of research seems to be relatively unexplored there is some evidence suggesting the results of maximal aerobic exercise testing and maximal anaerobic exercise testing may be related via energy pathways utilized during the tests (Jones & McCartney, 1986; Hawley & Noakes, 1992). This review will focus on the use and development of maximal, submaximal, and predictive exercise testing protocols for aerobic and anaerobic testing and how these two seemingly separate avenues of exercise testing may facilitate a predictive relationship between maximal aerobic and maximal anaerobic exercise testing.

Maximal Aerobic Capacity

Maximal oxygen uptake, maximal oxygen consumption, maximal aerobic capacity, and VO_2max are terms that can be used interchangeably in reference to cardiorespiratory fitness. Maximal oxygen consumption (VO_2max) represents the maximum amount of oxygen inspired, transported, and used for ATP production during exercise per minute (Akalan et al., 2004; Powers & Howley, 2009). The value of VO_2max is most often reported in terms relative to an individual's body weight in kilograms. This allows for comparisons between individuals with varied body weights. VO_2max is most commonly determined by direct measurement through a laboratory gas analysis system (Yoon, Kravitz, & Robergs, 2007) and is regarded as the superior method of cardiorespiratory fitness assessment according to the American College of Sports Medicine (ACSM, 1995). The use of VO_2max began with research in the early 1920s (Howley et al., 1995; Akalan et al., 2004). Exercise physiologists observed increases in workrate caused increases in oxygen consumption. However, it was A.V. Hill and his colleagues who discovered that there is a point at which oxygen consumption can no longer increase with an increase in workrate (Hill & Lupton, 1923). At the time of this discovery aerobic capacity testing occurred over several days due to equipment and standard gas analysis procedures. In the 1960s new innovations in expired air collection and gas analysis facilitated the use of continuous protocols through electronic gas analysis for instantaneous gas fraction determination (Buskirk & Taylor, 1954; Mitchell, Sproule, & Chapman, 1958; Bruce, Blackman, & Jones, 1963; Pollock et al., 1976). The phenomena discovered by A.V. Hill and his colleagues is attributed to the physiological limitations of the cardiorespiratory system and this point is now referred to as VO_2max. The point of VO_2max achievement is described as an observable plateau in oxygen consumption with an increase in workrate. This observation is the primary criterion used to ascertain the achievement of a true VO_2max. However, it is common to achieve a VO_2max without an observed oxygen consumption plateau, which requires the development and implementation of secondary criteria. This criteria includes blood lactate concentration, respiratory exchange ratio, and heart rate measurements at a predetermined percentage of age-predicted heart rate max (Howley et al., 1995; Akalan et al., 2004; Powers & Howley, 2009). The connection between VO_2max and cardiorespiratory fitness has made VO_2max testing the primary cardiorespiratory fitness assessment method for athletes and individuals with cardiovascular conditions. The popularity of VO_2max testing has also facilitated the development of standardized protocols on a wide array of modalities (Grant, Joseph, & Campagna, 1999; Akalan et al., 2004).

VO_2max Protocols

The type of test protocol widely considered superior at eliciting VO_2max is an incremental protocol. These protocols usually create an increase in workrate by either increasing speed, incline, or both on a treadmill modality or increasing resistance on a cycle ergometer modality at predetermined time intervals known as stages. VO_2max is reached by the systematic increase in workrate until the individual can no longer continue the desired power output which concludes the test protocol (Powers & Howley, 2009). Although a variety of modalities can be used to elicit a VO_2max, early studies showed that a treadmill protocol lasting 8-12 minutes yields the highest values (Akalan et al., 2004; Powers & Howley, 2009).

The optimal duration of VO_2max testing was discovered by Buchfuhrer and colleagues (1983). Utilizing both treadmill and cycle modalities, the findings of their research showed VO_2max tests lasting less than 8 minutes and longer than 17 minutes produced lower VO_2max test values in untrained individuals. Therefore, the recommendation for incremental test duration was set a 8-12 minutes. However, more recent studies have reinvestigated the optimal VO_2max test duration. In 2004, Astorino and colleagues found as little as 6 minutes could elicit true VO_2max test results in young adults. A few years later, Yoon et al. (2007) showed similar results for a cycle ergometer VO_2max testing protocol. This study found durations as low as 6-10 minutes produced higher VO_2max values compared to the standard 8-12 minute duration in trained individuals. Therefore, Yoon and colleagues (2007) concluded the duration of VO_2max testing is less important in less fit individuals. Based on the results of early and recent studies practitioners should be aware that more fit or trained participants may reach volitional fatigue earlier than their less fit or untrained counterparts.

A variety of modalities can be utilized to elicit VO_2max but previous research has shown treadmill incremental VO_2max protocols consistently produce the greatest VO_2max values by 10-20% compared to untrained cyclists and 6% compared to stepping protocols (Keren, Magazanik, & Epstein, 1980; Miles, Critz, & Knowlton, 1980; Storer et al., 1990; Powers & Howley, 2009). These protocols could involve walking, jogging, or running (American College of Sports Medicine (ACSM), 1995; Akalan et al., 2004) but all follow the same general principle. Participants, clients, or patients warm up at a self-selected pace that does not exceed the speed of the initial stage of the protocol. This warm up can vary between 3-5 minutes depending on the preference of the participant and practitioner. After the initial warm up, the speed is increased to a set speed determined by the practitioner or to a self-selected pace depending on the needs of the participant. The duration of each stage varies from 1-3 minutes which is also set by the practitioner and tailored to the individual being tested (ACSM, 1995). Once a stage is completed the speed, incline or both can be increased by a predetermined amount to increase the workload which increases the demand for oxygen and volume of consumed oxygen (VO_2max). The exercise continues using this systematic increase in workload until the participant can no longer produce the desired output.

Although incremental cycle ergometer VO_2max tests typically elicit lower VO_2max test values compared to treadmill protocols, cycle ergometry remains a popular testing modality. The lower VO_2max values are primarily due to less active musculature attributed to the non-weight bearing nature of cycling exercise compared to running exercise (Miles, Critz, & Knowlton, 1980; Storer et al., 1990; Powers & Howley, 2009). Reduced VO_2max values have been well documented during cycle ergometer VO_2max tests but they remain popular for a variety of reasons and follow similar principles as treadmill VO_2max tests. Participants are given a 3-5 minute warm up on the cycle, usually with no external resistance. Once the warm up is complete, the initial stage begins. However, in order to maintain a constant workload throughout each stage the pedal rate must remain consistent. The established pedal rate is 50 revolutions per minute (Astrand & Ryhming, 1954), but studies reinvestigating optimal pedal rate have found higher pedal rates may improve results in young adults (Beasley, Plowman, & Fernhall, 1989). A metronome is the most common method of maintaining pedal rate throughout the test. At the point pedal rate drops due to an increase in resistance the test is terminated and VO_2max is recorded. The initial workload or resistance applied to the cycle varies based on preferences of the participant and practitioner. Likewise, the magnitude of workload increase at the completion of each stage is also dependent on the preferences of the participant and practitioner (ACSM, 1995). The duration of cycle ergometer VO_2max tests follow the same recommendations addressed previously (Buchfuhrer et al., 1983; Akalan et al., 2004; Astorino et al., 2004; Powers & Howley, 2009; Yoon et al., 2007).

Innovations in VO_2max testing equipment have allowed the general principles of incremental exercise testing to be applied to sports specific modalities. The use of these sports specific protocols allows athletes engaging in these sports to obtain a VO_2max measurement during activity that closely matches the activity undertaken during training and competition. A few sports specific modalities include swimming, rowing, and nordic skiing. Direct measurement of VO_2max during swimming can be executed using three different methods. The first involves stationary swimming in an endless pool which produces current to swim against. This method requires the participant to wear a mask allowing inspiration of room air and analysis of expired air by gas analyzers similar to treadmill and cycling protocols. In order to increase the workload the current is increased a predetermined magnitude incrementally following completion of each stage until volitional fatigue. The second method involves expired gas analysis while the participant is wearing a mask during tethered swimming. This protocol measures the same variables as the first method but instead of swimming against a current the participant is tethered to the side of the pool. The participant is instructed to increase stroke pace a predetermined amount at the completion of each stage of the test (Costill, Maglischo, & Richardson, 1992). The test is terminated when the participant cannot keep the pace at which they are instructed to perform. The third method determines VO_2max from air samples taken immediately after completing a maximal swim. This method most closely mimics competitive swimming conditions. The participant swims 400 meters at maximal intensity and delays breathing about one stroke before the finish. Once finished a mask is immediately provided and participants breath into the mask for about 20 seconds (Costill, Maglischo, & Richardson, 1992). The air sample is collected in a Douglas bag, analyzed for VO_2 and VCO_2 and retrograde extrapolation techniques are used to determine VO_2max (Ribeiro, 1990).

The direct measurement of VO_2max in rowers and nordic skiers is similar to the protocols established for treadmill and cycle ergometer VO_2max testing. The major difference between these protocols is the equipment needed to complete the exercise. In order to evaluate the cardiorespiratory fitness of rowers using the same movements and musculature used during training and competition a stationary row machine is required. The protocol follows the same guidelines as the cycle ergometer in which participants are given a warm up and complete the incremental protocol immediately following the warm up period (Huntsman, DiPietro, Drury, Miller, & Todd, 2011). The incremental increases in workload during a rowing test also follow the same guidelines as the cycle ergometer protocol with systematic increases in external resistance. Similarly, nordic skiers complete the VO_2max test utilizing a specialized treadmill which is much wider to allow proper skiing motion. In laboratory settings roller skis are typically used to performed the test. Workload increases similar to a treadmill protocol through either increase speed, incline or both (Haug, Porcari, Brice, & Terry, 1999).

Although treadmill VO_2max exercise tests provide the highest values for the general population, there are circumstances in which sports specific tests will elicit higher values. Trained cyclists have been shown to achieve 12% higher VO_2max values through cycle ergometry compared to treadmill running (Ricci & Leger, 1983). Swimming VO_2max protocols have also been shown to produce 6% higher VO_2max values in trained swimmers compared to a treadmill protocol (Shono et al., 1993). Similarly, trained rowers and nordic skiers attain 4% and 3% higher VO_2max values compared to treadmill running respectively (Stromme, Ingjer, & Meen, 1977). Of course these results are specific to these specific athletes and sports specific VO_2max testing should be used with discretion in other populations.

Submaximal Exercise Testing

The connection between VO_2max and cardiorespiratory fitness has facilitated the development of submaximal exercise protocols to predict VO_2max for circumstances where a direct physical measurement of VO_2max is not physically or economically possible (Akalan et al., 2004). The direct measurement of VO_2max requires expensive equipment which is not easily accessible to the general population (Grant, Corbett, Amjadt, Wilson, & Aitchison, 1995). Direct measurements of maximal aerobic capacity may also increase the risk of an adverse cardiac event in individuals with cardiovascular conditions (Fitchett, 1985). Therefore, a variety of submaximal exercise tests have been developed to evaluate aerobic fitness including submaximal cycle ergometry, treadmill walking and running, multistage progressive shuttle running, recumbent stepping, and nonexercise prediction equations (Maritz JS, Morrison, Peter, Strydom, & Wyndham, 1961; Cooper, 1968; Ramsbottom, Brewer, & Williams, 1988; Ainsworth, Richardson, Jacobs, & Leon, 1992; George, Stone, & Burkett, 1997; McCulloch et al., 2015). VO_2max estimations from these protocols are used to categorize cardiorespiratory fitness based on normative data and provide baseline values. For individuals endeavoring to improve aerobic fitness these values could be used to track training adaptations, so it is important that results of submaximal exercise tests and prediction equations accurately reflect VO_2max values (George, Vehrs, Allsen, Fellingham, & Fisher, 1993).

Submaximal cycle ergometry has been a popular mode of assessing cardiorespiratory fitness. This method is relatively inexpensive, provides flexibility in testing intensity for varying fitness levels, and allows for testing of individuals with orthopedic or other contraindications to maximal exercise testing (Fox, 1973; Golding & Kasch, 1984; Siconolfi,Cullinane, Carleton, & Thompson, 1982; Meyers, & Sinning, 1989). The YMCA submaximal cycle test is one protocol predominately used to predict VO_2max values. This method uses stages of submaximal cycling at increasing submaximal power outputs to elicit submaximal heart rates. These heart rates can be used to predict VO_2max via nomogram or extrapolation techniques. The nomogram is based on sex and the highest exercise output along with exercise heart rate which correspond to maximal aerobic capacity. The extrapolation method uses a line of best fit across plotted submaximal heart rate data points and age predicted maximal heart rate. These graphic components correspond to maximal power output which is matched to estimated VO_2max from the YMCA prediction chart or calculated using the ACSM cycle ergometer metabolic equation (Astrand & Ryhming, 1954; Pollock, Wilmore, & Fox, 1984; Golding et al, 1989; ACSM, 1995). These methods of VO_2max prediction are tedious but the advancement of technology and computer programming has allowed the direct prediction of VO_2max utilizing regression equations (Beasley et al., 1989). These regression equations are comparable to other submaximal cycle test VO_2max values and show the nomogram and extrapolation methods have predictive accuracy for maximal oxygen consumption determined by cycle ergometry (Astrand & Ryhming, 1954). In contrast more recent validation research has discovered that submaximal cycle tests designed to predict VO_2max tend to overpredict VO_2max by 12% (Zwiren, Freedson, Ward, Wilke, & Rippe, 1991). The error observed in recent research can be attributed to baseline assumptions that must be made in order for these methods to be viable. The first assumption is that heart rate and oxygen consumption are linearly related. This is accurate at low submaximal exercise workloads but at higher workloads, 50-100% VO_2max, this assumption breaks down because maximal heart rate is typically attained before VO_2max (Grant et al., 1995). Secondly, it is assumed the oxygen cost during work done on an ergometer in constant but this may vary throughout submaximal intensities within a single cycle ergometer and between separate ergometers (Beasley et al., 1989). Exclusive to the extrapolation method, the general age predicted maximal heart rate equation tends to underestimate the actual value in the elderly population while overestimating in younger populations (Cleary et al., 2011). The submaximal heart rate measurements required during these testing protocols may also be affected by daily heart rate variation which could alter the accuracy of these predictive methods (Rowell, Taylor, & Wang, 1964; Davies, 1968; Hartung, Blanco, Lally, & Krock, 1995; Swain & Wright, 1997).

The variety of submaximal treadmill predictive protocols is staggering. Similar to submaximal cycle ergometry, extrapolation can be used during treadmill walking or running protocols. These protocols follow the same general guidelines as cycle ergometry. Three to four submaximal workloads are used to elicit submaximal heart rates which are represented graphically. A line of best fit across these data points and plotted age predicted maximal heart rate determine maximal workload matched with predicted maximal oxygen consumption. The same limitations which plague the extrapolation method during submaximal cycle ergometry also affect the predictive accuracy of treadmill protocols (Pollock et al., 1976; McArdle, Katch, & Katch, 1991; ACSM, 1995). Other predictive treadmill protocols use the assumed linear relationship between oxygen consumption and workrate and the linear relationship of workrate to test duration to indirectly relate oxygen consumption to test duration (Storer, Davis, & Caiozzo, 1990). These exercise tests are somewhat maximal because they require participants to walk or run as far as possible for a predetermined amount of time. The Cooper walk/run test is a commonly used submaximal exercise test which applies this concept. Participants cover as much distance as possible in 12 minutes, therefore the results are highly dependent on individual motivation. However, studies have shown the Cooper test is highly correlated to VO_2max in large test groups (Cooper, 1968; Grant et al., 1995; O'Donnell, Smith, O'Donnell, & Stacy, 1984). Results of more recent research showed the Cooper test overpredicted VO_2max by 9% in men, but results of large group testing consisting of men and women remain highly correlated and reliable (Zwiren et al., 1991). The implementation of submaximal prediction tests should be used with discretion when applied to different populations because validity and reliability in one population does not guarantee the same results in more or less homogenous populations (Kline et al., 1987).

The Bruce treadmill protocol is another predictive exercise test without direct gas analysis measure of oxygen, which requires participants to complete as much work as possible in a given amount of time. The Bruce protocol consists of 7 stages lasting 3 minutes each beginning with submaximal treadmill walking at a predetermined incline. The progression through stages involves incremental increases in speed and incline. Throughout the protocol heart rate is measured along with blood pressure and rate of perceived exertion (RPE). Participants are encouraged to complete as many stages as possible and the test is terminated when participants are fatigued. In order to predict VO_2max, metabolic equivalents are calculated for each stage and plotted against heart rate (Bruce et al., 1963). The predictive accuracy of this method is high through stage 4 with a predictive error of 3 ml/kg/min (Pollock et al., 1976; Liang, Alexander, Stull, Serfass, & Wolfe, 1985).

Treadmill walking and cycle ergometer submaximal exercise tests tend to be the preferred modalities for a variety of populations. However, treadmill running or jogging protocols may be more suited for younger populations that prefer this modality for training. The use of treadmill submaximal exercise protocols to predict VO_2max are usually multistage. These methods are time consuming and require data collection at several time intervals (Hermiston & Faulkner, 1971; Town & Golding, 1977). Currently, a single stage treadmill jogging protocol has been developed to predict VO_2max (George et al., 1993). This protocol requires participants to jog at a submaximal speed corresponding to ~70% VO_2max and ~80-85% HRmax at 0% incline. The speed is determined at the beginning of the protocol and remains constant throughout the test along with incline. Heart rate measurements are taken throughout the protocol until steady state is reached (~3 minutes). Researchers developed a multiple regression equation to predict VO_2max from steady state heart rate and treadmill speed along with correlated demographic variables. Compared to other predictive methods and modalities this equation provides similar results. However, it should be noted that participants need a VO_2max of at least 35 ml/kg/min and be 18-29 years old in order to minimize predictive error. Therefore, the use of this submaximal treadmill protocol and prediction equation in older and lower fitness populations should be used with consideration prior to administration (George et al., 1993). A more recent study aimed to validate this protocol and equation against a larger population with participants older than 29 years. This study found that the original prediction equation successfully predicted VO_2max in older participants. Therefore, this method of predicting VO_2max is accurate for a new age range of 18-40 years old (Vehrs, George, Fellingham, Plowman, & Dustman-Allen, 2007).

Although cycle and treadmill modalities tend to be preferred for VO_2max prediction there are a variety of other protocols and modalities that can be applied to a wide range of populations. Similar to the Cooper walk/run test, a multistage progressive shuttle test (MST) is preferred when testing a large group of participants simultaneously. Likewise, it is also somewhat maximal in nature. Participants are instructed to run between two markers 20 meters apart in time with a sound signal which increases in frequency every minute of the protocol. When the participant is no longer able to keep the pace on three occasions the test is terminated and VO_2max is determined by the number of shuttles attained at a particular level of the protocol (Ramsbottom et al., 1988). This testing protocol compares favorably with other submaximal exercise protocols. Other modalities have also been developed using recumbent stepping and RPE in individuals with spinal cord injuries which successfully predict VO_2max in this population (McCulloch et al., 2015). This type of predictive method is also useful in other populations in which maximal and standard submaximal exercise protocols would be contraindicated. Finally, there are certain situations and conditions which all types of exercise testing are contraindicated or unavailable such as extremely large epidemiological studies requiring maximal aerobic capacity. In these cases nonexercise prediction equations have been developed and modified for various populations (Jackson et al., 1990; Ainsworth et al., 1992; George, Heil et al., 1995; Stone, & Burkett, 1997; Malek, Housh, Berger, Coburn, & Beck, 2004; Malek, Housh, Berger, Coburn, & Beck, 2005).

Maximal Anaerobic Capacity

Athletic performance is often thought to be primarily dependent on maximal aerobic capacity. However, many athletic activities also rely on speed, strength and power which depend on maximal anaerobic capacity. Maximal anaerobic capacity is the maximal amount of adenosine triphosphate (ATP) resynthesized through anaerobic metabolism during fast, explosive, short duration activities (Green & Dawson, 1993). This occurs in two processes, hydrolysis of creatine phosphate and anaerobic glycolysis which leads to accumulation of lactate and pyruvate molecules. Theoretically, based on these subcomponents the contribution of each separately could be determined during maximal anaerobic activities. This would allow researchers and practitioners to determine maximal anaerobic power and maximal anaerobic capacity separately. However, after a few seconds of initial maximal activity these two systems supply energy simultaneously in varying percentages based on activity duration. This does not easily facilitate exercise tests for anaerobic power and capacity separately (Vandewalle, Peres, &

Monod, 1987). Therefore, exercise tests which measure power and capacity will be addressed collectively further on in this literature review.

Anaerobic Power Protocols

Maximal anaerobic capacity can be assessed through a wide variety of laboratory and field modalities. The superior method of anaerobic capacity assessment is often considered the Wingate cycle test (Patton & Duggan, 1985; Ayalon. Inbar, & Bar-Or, 1974). First developed at the Wingate Institution in Israel, the Wingate cycle test is a supramaximal protocol eliciting peak power, mean power, and fatigue index during cycle pedaling against resistance for 30 seconds (Bar-Or, Dotan, Inbar, 1977; Patton, Murphy, & Frederick, 1984; Bar-Or O, 1987; Inbar, Bar-Or, & Skinner, 1996; Powers & Howley, 2009). Similar to other anaerobic test modalities and protocols the Wingate cycle test is designed to evaluate the maximal capacity of the energy systems being utilized by the active musculature during the test (Patton & Duggan, 1985; Powers & Howley, 2009). The use of the Wingate cycle test is often performed in individuals engaging in anaerobic training. This may include sprint/jump athletes, soldiers, firefighters, and other groups that engage in intermittent anaerobic activity (Patton & Duggan, 1985). The protocol requires a weighted cycle ergometer with the ability to apply a predetermined weight resistance, 7.5% body weight, instantly to the flywheel (Patton et al., 1984; Patton & Duggan, 1985). The purpose of the Wingate cycle test is to perform as many pedal revolutions in 30 seconds with the predetermined resistance applied to the flywheel (Patton et al, 1984; Patton & Duggan, 1985; Powers & Howley, 2009). The pedal revolutions are recorded in 5 second intervals which allow calculation of peak power, mean power, and fatigue index. Typically anaerobic power is greatest during the first portion of the test, recorded as peak power, and decreases as the test progresses, eliciting lower mean power values. The difference in power output during the test is observed as the fatigue index which indicates anaerobic endurance (Bar-Or et al., 1977; Powers & Howley, 2008). Through its development and use in research, anaerobic power results obtained during the Wingate cycle test have been correlated with other established laboratory and field anaerobic capacity assessments (Patton & Duggan, 1985). Patton and Duggan (1985) found mean power (MP) and peak power (PP) output results from the Wingate cycle test were correlated to power output results from 50 meter sprinting (MP: $r= -0.672$, $p<0.01$; PP: $r= -0.527$, $p<0.05$) and the Margaria step test (MP: $r= 0.866$, $p<0.001$; PP: $r= 0.620$, $p<0.05$). The results from the Wingate cycle test are highly reliable ($r> 0.90$) and valid ($r= 0.79$; $r= 0.83$) for measures of anaerobic capacity but also highly depend on participant motivation (Geron & Inbar, 1980; Bar-Or O, 1987; Vandewalle et al., 1987; Powers & Howley, 2009).

Although the 30 second Wingate cycle test is considered the superior method of assessing maximal anaerobic capacity there are objections to testing athletes that do not engage in 30 second maximal effort activities (Sinnett, Berg, Latin, & Noble, 2001). Shorter duration Wingate cycle protocols have also been suggested to reduce adverse hypoglycemic and lactate accumulation symptoms experienced following the standard 30 second protocol (Allen, Westerblad, Lee, & Lannergren, 1992; Vincent et al., 2004). Previous research has shown power values obtained in the 20th and 30th seconds of a Wingate cycle test are highly correlated. Therefore, a 20 second Wingate protocol is thought to yield similar results as the standard 30 second test while reducing adverse symptoms (Vandewalle, 1987). Results show peak power was similar between the protocols while mean power and fatigue index were lower. This is expected due to the 10 second reduction in duration, but the 20 second variables successfully predicted the power values in the last 10 seconds of the 30 second protocol. Implications of these results include improved participant adherence and reduced adverse effects of the standard 30 second test (Laurent, Meyers, Robinson, & Green, 2007). Additionally, Wingate cycle protocols lasting less than 20 seconds have been proposed to better serve the elderly population. This protocol is half the duration of a standard protocol at 15 seconds (Bar-Or, Berman, & Salsberg, 1992). This short protocol reduced unpleasant symptoms in this population which could increase adherence and repeatability. The peak and mean power output measures were valid for this protocol which indicates this protocol may provide reliable results over time in order to track changes in maximal power output in the lower extremities. Unsurprisingly, peak power output was correlated with the 30 second protocol and results showed that peak power output values differed no more than 1% (Nevill & Atkinson, 1997). The surprising result involved the correlation of mean power output from the 15 second protocol with those obtained by the 30 second protocol. This suggests that mean power output from a protocol half the duration of the standard protocol can successfully represent anaerobic capacity (Sinnett et al., 2001).

Similar to aerobic fitness testing there are a variety of modalities which elicit anaerobic power measurements including field tests. Two field tests commonly utilized are stair climbing and vertical jumping. The first anaerobic stair climbing test was proposed in 1966 by Margaria, and colleagues. These researchers proposed maximal anaerobic power could be found by calculating power output during a stair climbing protocol at maximal speed. This protocol involved sprinting up stairs ~17.5 cm tall at maximal speed after a short 2 meter run on a level surface. The time taken to climb an even number of stairs was measured using an electronic clock sensitive to 0.01 second. This electronic clock is driven by two switchmats, one which initiated timing and the other stopping the clock on contact. More recent investigations often utilize timing gates rather than swtichmats. The duration between switchmat contact is used to calculate maximal anaerobic power. Another researcher, Kalamen, proposed a modification to this protocol with participants climbing stairs three at a time rather than two. However, validity and reliability studies showed the two step protocol elicited higher power output values (Margaria, Aghemo, & Rovelli, 1966). As research continued, modifications to elicit higher power output during this stair climbing protocol were proposed and investigated. A factor that affects maximal power output is optimal resistance. Research shows that an increased external load of 40% body weight during stair climbing increased maximal power output by 16% (Kyle & Caizzo, 1985), similarly application of an external load of 33% of body weight increased stair climbing maximal power output by 10% (Kitagawa, Suzuki, & Miyashita, 1980).

The vertical jump test was first presented by D. A. Sargent in 1921 "as the 'physical test of a man' …. as a measure of general muscular power" (Sargent, 1924). The estimation of power output during vertical jump requires the determination of work which is dependent on a time component. This time component creates wide variability between various prediction equations for vertical jump testing. When using these methods assumptions must be made that may not be true including: 1) the initiation of the time component and 2) the work accomplished and force produced remain constant throughout the jump. Due to these sources of potential error the height of the vertical jump is the best predictive variable based on high correlation between jump height and power output obtained by force plate testing (Davies & Rennie, 1968; Offenbacher, 1970; Davies, 1971; Vandewalle et al., 1987). Since the inception of vertical jump testing, a variety of protocols have been developed and most allow an arm swing. Differences typically stem from initial position either knees bent at 90° or counter movement at the knees upon initiation of the jump (Vandewalle et al., 1987). Contrary to stair climbing, maximal power output is hindered during vertical jumping by external loading (Davies & Young, 1984). The use of these anaerobic exercise tests, laboratory and field based, should be sports specific based on athletic activities and practicality of results to researcher, coaches and athletes (Vandewalle et al., 1987).

Anaerobic Prediction Methods

Submaximal methods of predicting maximal anaerobic capacity are rare. The ultra short duration of maximal anaerobic capacity tests may account for this lack of submaximal prediction equations. Methods utilizing predictive equations for maximal anaerobic power tend to require maximal effort such as vertical jump. Anaerobic tests often require 30 seconds or less to complete which may not necessitate predictive methods which are usually created in order to conserve time during testing large amounts of participants. However, anaerobic indices have been used as predictor variables of aerobic power and performance (Hachana, Attia, Nassib, Shephard, & Chelly, 2012). The modalities typically investigated are endurance running and cycling. The primary modality of prediction is the Wingate cycle test. Studies have shown a significant relationship between anaerobic performance as early as 15 seconds up to 30 seconds and aerobic power (Hakkinen, Rahkila, & Alen, 1985). However, other studies have shown a weak relationship between these variables. These mixed results suggest that perhaps fatigue index will show a better relationship because high aerobic power will produce higher overall anaerobic power throughout the test resulting in a smaller rate of decline in power output (Vandewalle, Gilbert & Monod, 1987). The inconsistencies observed may be due to the type of athlete and training, with some athletes showing positive relationships while in others show no relationship (Crielaard & Pirnay, 1981). The mixed results of these studies indicate there might be a relationship between anaerobic power indices and aerobic performance which could be elucidated by examination of the energy production pathways governing each type of activity.

Energy Production Pathways

The purpose of developing and implementing maximal exercise tests is to ultimately evaluate the capacity of the energy system utilized during the activity. During VO_2max testing, substrate utilization is used to indicate which fuel source, carbohydrate or fat, is being chemically consumed for ATP production. Respiratory exchange ratio (RER) is the method used to determine substrate partitioning during a VO_2max test and is a ratio between the amount of carbon dioxide produced through substrate metabolism to the amount of oxygen consumed. This ratio allows for the distinction between the percentage of carbohydrate and fat break down during exercise. The percentage of carbohydrate and fat utilization depends on exercise intensity. At low exercise intensities (<30% VO_2max) fat is the primary fuel source for ATP production and at high exercise intensities (>70% VO_2max) carbohydrate is the primary fuel source. During the onset of VO_2max testing the RER values tend to be low indicating the majority of fuel contribution originates from fat. A lower RER value during the VO_2max test also indicates the energy pathway which is being utilized. An RER <0.80 corresponds to primarily fat oxidation through aerobic glycolysis and oxidative phosphorylation. As individuals progress through an incremental VO_2max test the workrate increases which increases the exercise intensity. This increase in exercise intensity corresponds to a shift from primarily fat oxidation to carbohydrate break down. The "crossover point" for substrate utilization tends to occur at an exercise intensity of 40% VO_2max and corresponds to an RER between 0.80-0.85. At or near this "crossover point" the ratio of fat and carbohydrate utilization is about half and there is about a 50/50 use of aerobic and anaerobic energy pathways. As the test progresses beyond the "crossover point" anaerobic glycolysis becomes the primary pathway for energy production. RER continues to rise with increases in workrate and exercise intensity. At or near VO_2max the RER value will be ≥1.0

with 1.15 generally accepted as true VO_2max achievement. This RER value also indicates the energy produced to perform the work at the end of the test is solely from carbohydrate break down utilizing only anaerobic glycolysis (Powers & Howley, 2009). Based on the progression of a VO_2max test both aerobic and anaerobic energy pathways are utilized in order obtain maximal oxygen consumption.

The purpose of assessing anaerobic capacity through laboratory and field anaerobic tests is to evaluate the capacity of anaerobic energy pathways to produce ATP required to complete the test. Similar to the superior maximal aerobic exercise test, VO_2max, the superior maximal anaerobic exercise test, Wingate Anaerobic Cycling, has two phases of energy production. During the first phase of a Wingate cycle test endogenous ATP and the phosphagen (ATP-PC) system are the primary ATP providers for active musculature. Peak power determination during the beginning of the Wingate cycle test indicates the maximum rate endogenous ATP is utilized and re-synthesized by the ATP-PC system. Likewise other ultra short duration anaerobic tests lasting less than ~10 seconds primarily determine the capacity of the ATP-PC system to resynthesize ATP. The second phase is a combination of energy production pathways utilized for the duration of tests lasting longer than 10 seconds. During the Wingate cycle test the decline in power through the duration of the test, reported as fatigue index, is believed to represent the production of ATP using both the ATP-PC system and anaerobic glycolysis (Powers & Howley, 2009). Based on the development of exercise testing to evaluate the capacity of the energy pathway utilized during the test it becomes apparent that aerobic and anaerobic test results may be related. Specifically, at the point when the results of a VO_2max test and Wingate test are obtained it appears that each test utilizes the same energy pathways. Based on energy pathways used at the end of a VO_2max test and during a Wingate cycle test there may be a potential relationship that could facilitate the prediction of VO_2max from a Wingate cycle test.

Relationship of Aerobic and Anaerobic Indices

Minimal research has attempted to directly link measures of aerobic and anaerobic capacity from each respective exercise testing method. Research conducted by Jones and McCartney (1986) examined the relationship between anaerobic power and aerobic performance. These researchers found a correlation between work done from a 30s cycle protocol and VO_2max obtained from a cycle protocol. A regression equation was developed to enable the prediction of VO_2max performance from 30s anaerobic cycle measures. However, the prediction equation developed by Jones and McCartney (1986) was derived from a sedentary population and VO_2max was assessed using a cycle protocol rather than a treadmill protocol, which elicits higher VO_2max values. Another study conducted by Hawley and Noakes (1992) aimed to discover a relationship between peak power output and VO_2max obtained through anaerobic and aerobic cycle protocols. Results showed that peak power and VO_2max are highly correlated in trained cyclists. Based on these results it appears that peak power output can accurately predict VO_2max in this population (Hawley & Noakes, 1992). To date no other research has attempted to predict treadmill VO_2max values from Wingate cycle test anaerobic power values. However, based on previous studies conducted it appears a relationship exists between these variables but has not been explored utilizing a treadmill VO_2max protocol, therefore there is a gap in the existing literature.

Conclusion

Since the 1920s, exercise physiologists have endeavored to create standardized maximal aerobic and anaerobic exercise testing protocols (Taylor et al., 1995). A variety of maximal aerobic exercise tests have been developed for a wide array of modalities. The development of standard maximal aerobic exercise tests also triggered the development of a vast number of submaximal exercise test protocols on a multitude of different modalities, allowing the prediction of maximal aerobic capacity from less strenuous submaximal exercise intensities.

Contrary to maximal aerobic capacity testing which has facilitated the development of numerous submaximal predictive test protocols there are very few, if any, submaximal predictive methods for maximal anaerobic capacity. The majority of maximal anaerobic exercise test protocols measure variables in a field setting which are highly correlated to measures of power output obtained via criterion laboratory methods. In a majority of exercise physiology research, maximal anaerobic capacity is used as a predictive variable for aerobic performance. This suggests maximal aerobic and anaerobic capacities are related. At the point of maximal aerobic and anaerobic capacity test termination energy production systems are similar, suggesting maximal anaerobic capacity may successfully predict maximal aerobic capacity. There has only been one study to produce a prediction equation using maximal anaerobic indices obtained from a 30 second cycle protocol to predict maximal aerobic capacity. However, this study measured maximal aerobic capacity using cycle ergometry rather than a treadmill protocol. According to current research no other study has attempted to create a prediction equation for maximal aerobic capacity obtained through a treadmill protocol from maximal anaerobic cycling which is the desired outcome of the current study.

CHAPTER 3

METHODOLOGY

Subjects Characteristics

A total of 72 participants were recruited to participate in the study protocol from University of Nevada, Las Vegas student population through word of mouth. 64 participants (men n = 32, women n = 32, Table 1) completed the study protocol and attained a true VO_2max (defined below), eight were unable to satisfy VO_2max criteria. In order to be admitted into the research study the participants had to meet inclusion criteria: male 18-44 years of age or female 18-54 years of age, and classified as "low risk" according to the ACSM Health Risk Questionnaire. Participants were excluded from the study if they were <18 years of age, male >44 years of age, female >54 years of age, classified as "moderate risk" according to the ACSM Health Risk Questionnaire or had an implantable device (such as a Pacemaker), or had orthopedic, cardiovascular, respiratory, or metabolic conditions. All participants provided written informed consent after completing the ACSM Health Risk Questionnaire and prior to commencing the UNLV Institutional Review Board approved study protocol (#819974).

Table 1. Participant demographics

	Male	Female	Significance
n	32	32	*p-value*
Age (yrs)	25.56 ± 5.66	25.06 ± 5.96	p=0.732
Height (cm)	175.01 ± 7.46*	162.88 ± 6.23*	p<0.001
Weight (kg)	78.22 ± 11.31*	60.82 ± 7.07*	p<0.001
VO_2max ($L \cdot min^{-1}$)	4.09 ± 0.61*	2.69 ± 0.48*	p<0.001
Peak power (W)	784.53 ± 221.78*	453.53 ± 124.10*	p<0.001
Mean power (W)	526.78 ± 133.56*	316.22 ± 93.76*	p<0.001
Fatigue index (%)	48.13 ± 10.85*	36.84 ± 14.82*	p<0.001
Body fat (%)	14.35 ± 5.43*	23.63 ± 4.83*	p<0.001
Physical activity ($METmins \cdot wk^{-1}$)[a]	5592.61 ± 2974.86	7114.21± 14234.17	p=0.582
Physical activity category[a,b]	High	High	p=0.058

* Significant difference between males and females
[a] Determined by IPAQ-long form
[b] Categories: Low, Moderate, High

Collection of Data

Participants reported to the UNLV Exercise Physiology Laboratory on one occasion to complete the study protocol. They were instructed to wear athletic attire, abstain from alcohol consumption at least 6 hours prior to testing, refrain from eating a large meal or consuming caffeine 2 hours prior to testing, and to be well hydrated. Participants were also instructed to refrain from engaging in vigorous exercise 24 hours prior to their scheduled testing session. Demographic information (age, sex, height, and mass) of qualifying participants was recorded prior to testing through self-report (age, sex), stadi-o-meter (Novel Products, Inc., Rockton, IL) (height), and scale (Mettler Toledo #2184, Columbus, OH) (body mass) respectively. Body composition was determined by the seven-site skinfold method using skinfold calipers (Baseline Skinfold Caliper 12-1110, Fabrication Enterprises, White Plains, NY) and lower body girths were measured using a cloth tape measure. The VO_2max test was completed using a metabolic cart system comprised of a treadmill able to increase speed and grade (L7, Landice, Randolph, NJ), a Hans-Rudolph valve/mouthpiece and a metabolic gas analyzers and software (Moxus, AEI Technologies, Pittsburgh, PA). All necessary calibrations were completed prior to each exercise test. Heart rate was also measured during the VO_2max test using a Polar heart rate monitor (Polar H7, Polar Electro, Lake Success, NY) aligned with the base of the sternum with the strap adjusted appropriately to reduce slippage during the test. Peak power, mean power, and fatigue index were measured using a Wattbike (Wattbike Pro, Wattbike, Nottingham, UK) programmed with the 30 second Wingate cycle test.

After all necessary documentation, anthropometric measurements, and calibrations were completed participants were fitted with a Polar heart rate monitor, headgear and mouthpiece. Once properly fitted, participants were connected to the MOXUS metabolic gas analysis system.

Participants were given a 3 minute warm up period at 80.4 m/min (3 mph) and 0% grade. After the warm up period, participants followed a similar protocol used by Montes, Wulf, and Navalta (2017) with a slight modification to the incremental increases in self-selected comfortable running speed. Speed was increased 13.4 m/min (0.5 mph) every minute until self-selected comfortable running speed was attained. All participants were given similar verbal encouragement throughout the test. At test termination speed and grade were decreased to 67.1 m/min (2.5 mph) and 0% grade respectively. Participants were given a 3-5 minute cool down period following test termination. Attainment of a true VO_2max included meeting at least two of the following criterion: termination due to volitional fatigue, RER >1.05, and heart rate ±10 bpm of age predicted maximal heart rate (HRmax = 220-age). VO_2max data were recorded using the Moxus metabolic software (AEI Technologies, Pittsburg, PA, USA) and stored in a secure area of the laboratory.

Following the VO_2max exercise test, participants were given 15-20 minutes to complete the International Physical Activity Questionnaire-long form (IPAQ-long). This measure of physical activity level was used as a demographic variable. Once the IPAQ-long was complete, participants began the second portion of the testing session. During this portion of the session, participants were instructed to adjust the seat height of the Wattbike so their knee was slightly bent at the point of fullest extension (approximately a 5 degree bend). Once adjusted, participants were given a 3-minute warm up period with air and magnetic resistance set at 1. After the warm up period, participant’s mass was input into the 30” cycle test program to determine the amount of resistance to be applied to the flywheel during the test. Air and magnetic resistance settings were given by the test program based on each participant's mass and resistance was adjusted according to program specifications. Participants were instructed to continue pedaling throughout this process. Once the resistance was adjusted the test initialized and participants were instructed to increase pedal rate until the initiation of the test. After the initializing process and a 5-second countdown the test began and all participants were given appropriate encouragement for the duration of the test (30 seconds). At the completion of the test participants began a 3-5 minute cool down period against air and magnetic resistance of 1. Peak power, mean power, and fatigue index were recorded and stored in a secure area of the laboratory until data analysis.

Statistical Analysis

All metabolic data, VO_2 and VO_2/kg, was collected on the Moxus software. Power output data was collected on the Wattbike including peak power (W), mean power (W), and fatigue index (%). Skinfolds, thigh girth, hip girth, and resting heart rate (RHR) were all taken manually as these measurements were separate from both the Moxus system and Wattbike. Descriptive statistics were conducted on demographic and anthropometric variables and reported as mean ± standard deviation (SD). Demographic and anthropometric differences between men and women were compared using unpaired t-tests. Multiple linear regression utilizing a hierarchical entry method was used to generate gender-independent and gender specific equations using VO_2max (L/min) as the dependent variable. Independent or predictor variables were entered into the regression model based on 1) theoretical background and 2) predictive power on VO_2max determined by Pearson's product-moment correlation. Predictor variables exhibiting multicollinearity ($r > 0.9$) were excluded from further analysis. The accuracy of the regression models was assessed using standard error of estimate (SEE) and percentage of SEE (SEE%). Stability or validity of each regression model was determined by predicted residual sum of squares (PRESS) statistics. All statistical analyses were conducted using IBM SPSS Statistics 22 software (IBM SPSS Statistics 22, IBM Corporation, Armonk, NY). Significance was accepted at the $p \leq 0.05$ level.

CHAPTER 4

RESULTS

Gender-independent

Previously established variables associated with VO_2max including peak power (PP), height, weight, and sex (Jones & McCartney, 1986; Hawley & Noakes, 1992) were significantly correlated to VO_2max. Other previously un-investigated variables including mean power (MP), fatigue index, percent body fat, thigh skinfold, triceps skinfold, thigh girth, hip girth, and resting heart rate (RHR) were also significantly correlated to VO_2max (Table 2).

Table 2. Pearson's product-moment correlation for gender-independent model

Predictor variable	Pearson's r	Significance (*p*-value)
Sex	**-0.79**	**<0.001**
Age (yrs)	-0.11	0.368
Height (cm)	**0.74**	**<0.001**
Weight (kg)	**0.74**	**<0.001**
Chest skinfold (mm)	-0.06	0.630
Axilla skinfold (mm)	-0.08	0.543
Triceps skinfold (mm)	**-0.53**	**<0.001**
Subscapular skinfold (mm)	-0.04	0.742
Abdominal skinfold (mm)	-0.02	0.892
Suprailliac skinfold (mm)	-0.07	0.611
Thigh skinfold (mm)	**-0.56**	**<0.001**
Percent body fat	**-0.60**	**<0.001**
Thigh girth (cm)	**0.42**	**0.001**
Hip girth (cm)	**0.35**	**0.005**
RHR (bpm)	**-0.28**	**0.023**
PP (W)	**0.78**	**<0.001**
MP (W)	**0.77**	**<0.001**
FI	**0.36**	**0.004**

Note: Pearson's r correlations between VO_2max (L/min) and predictor variables.
Bold values are the significant predictor variables as provided by SPSS

Assessment of multicollinearity between predictor variables revealed a high correlation between PP and MP (r = 0.96). Based on previous research (Tanner & Navalta, 2016) MP was excluded due to similar individual correlation between these variables and VO_2max (PP: r = 0.78; MP: r =

0.77). The remaining predictor variables were entered hierarchically into the regression analysis (Figure 1).

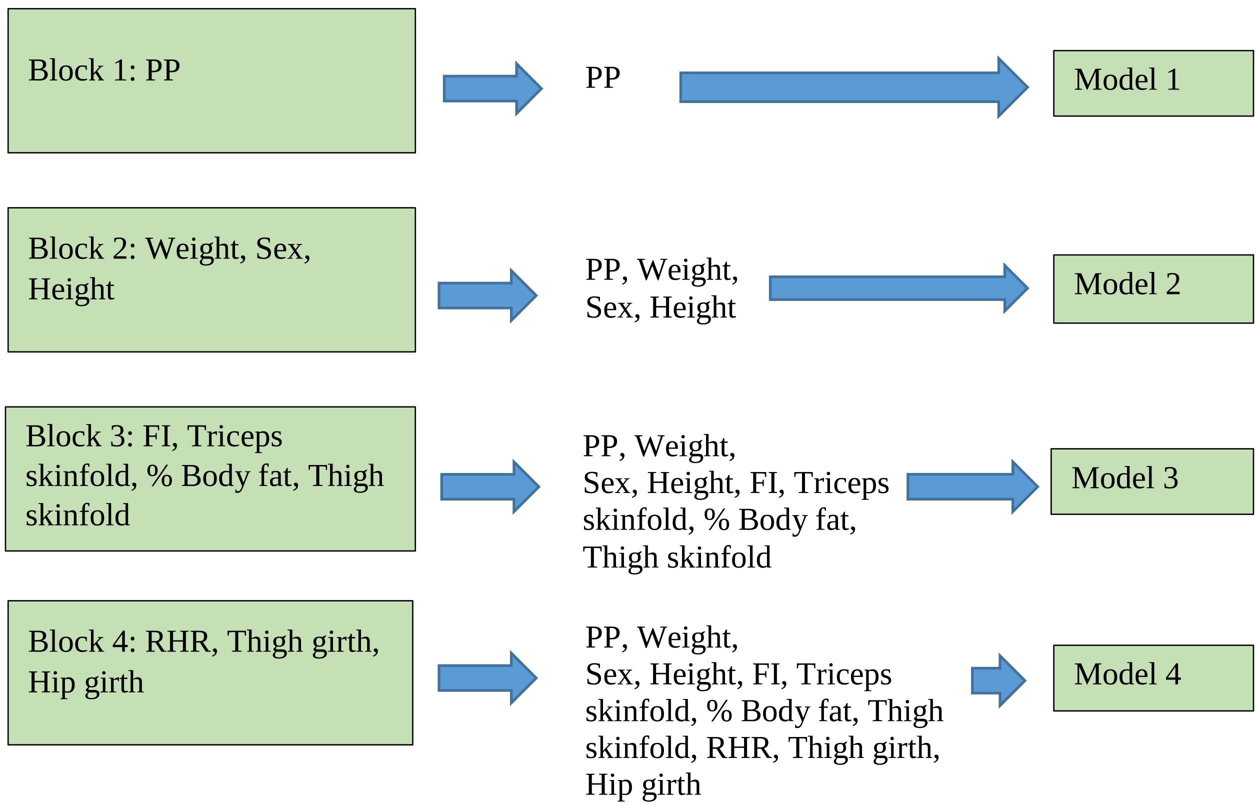

Figure 1. Hierarchical multiple regression variable entry for gender-independent model

Assessment of individual predictor variables revealed height, sex, thigh skinfold, triceps skinfold, fatigue index, thigh girth, and hip girth did not significantly contribute to the predictive power of the model (height: t = -0.41, p = 0.686; sex: t = -0.24, p = 0.810; thigh skinfold: t = -0.36, p = 0.723; triceps skinfold: t = 1.38, p = 0.174; fatigue index: t = -0.48; p = 0.633; thigh girth: t = 1.38, p = 0.175; hip girth: t = 0.87, p = 0.389). Model summary provided in Table 3.

Table 3. Multiple linear regression model summary for gender-independent model

Model	R	R^2	Adjusted R^2	SEE
1	0.775[a]	0.601	0.595	0.568
2	0.877[b]	0.768	0.753	0.444
3	0.900[c]	0.811	0.783	0.416
4	0.927[d]	0.859	0.830	0.369

a. Predictors: PP
b. Predictors: PP, weight, sex, height
c. Predictors: PP, weight, sex, height, FI, triceps skinfold, percent body fat, thigh skinfold
d. Predictors: PP, weight, sex, height, FI, triceps skinfold, percent body fat, thigh skinfold, RHR, thigh girth, hip girth

A second analysis was conducted without these predictor variables. The remaining variables were entered into the regression model individually in the same manner described above (Figure 2). Model summary provided in Table 4. Individual predictor assessment revealed all predictors significantly contribute to the prediction of VO_2max (PP: $t = 2.276$, $p = 0.026$; weight: $t = 7.570$, $p = <0.001$; % body fat: $t = -6.729$, $p = < 0.001$; RHR: $t = -3.691$, $p = < 0.001$). The following multiple regression model was generated from PP, weight, percent body fat, and RHR:

$$\hat{Y} = 2.627 + (0.001\times PP) + (0.037\times weight) + (-5.315\times percent\ body\ fat) + (-0.019\times RHR)$$

where PP is measured in watts, weight is measured in kilograms, percent body fat is the fractional form, and RHR is measured in bpm. A scatter plot of predicted vs. observed VO_2max values for the gender-independent model is provided in Figure 3. Accuracy for this model determined by SEE and SEE% were 0.37 (L/min) and 10.89% respectively. Comparison of PRESS statistics (R^2_{PRESS} and SEE_{PRESS}) indicates this model is valid ($R^2 = 0.841$ vs. $R^2_{PRESS} = 0.782$; $SEE = 0.37$ vs. $SEE_{PRESS} = 0.41$).

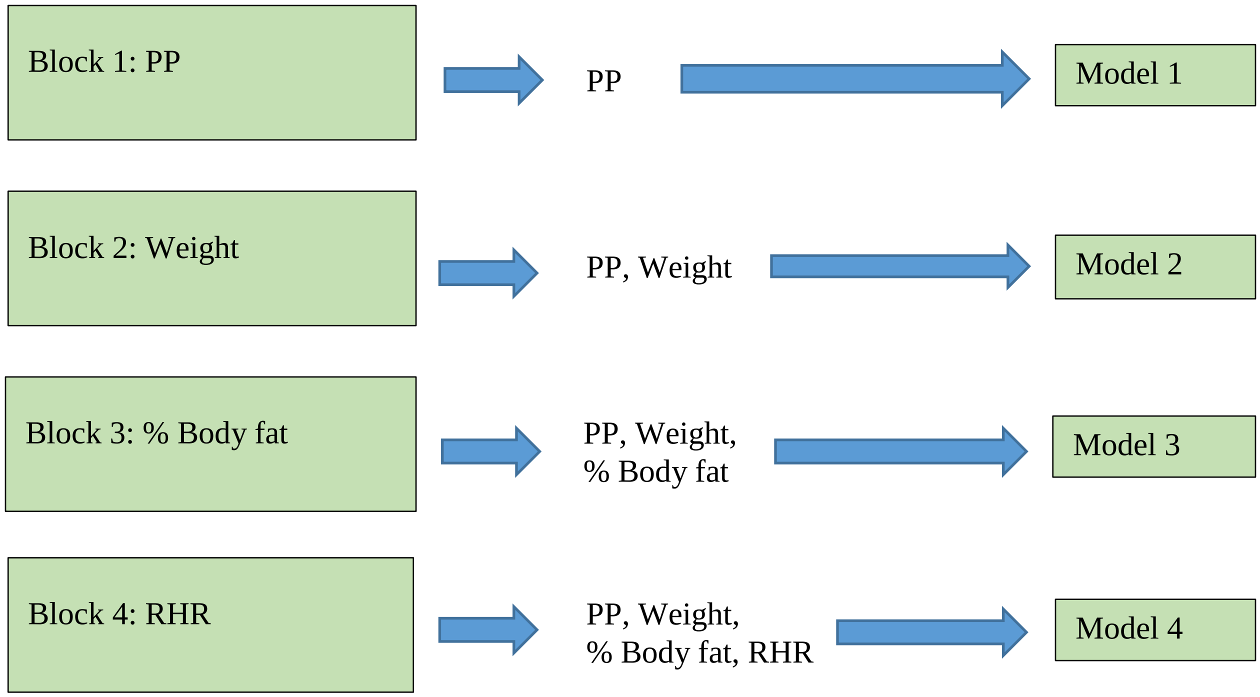

Figure 2. Hierarchical multiple regression variable entry for gender-independent model

Table 4. Multiple linear regression model summary for gender-independent model

Model	R	R^2	Adjusted R^2	SEE
1	0.775[a]	0.601	0.595	0.568
2	0.833[b]	0.693	0.683	0.503
3	0.897[c]	0.805	0.795	0.404
4	0.917[d]	0.841	0.830	0.368

a. Predictors: PP
b. Predictors: PP, weight
c. Predictors: PP, weight, percent body fat
d. Predictors: PP, weight, percent body fat, RHR

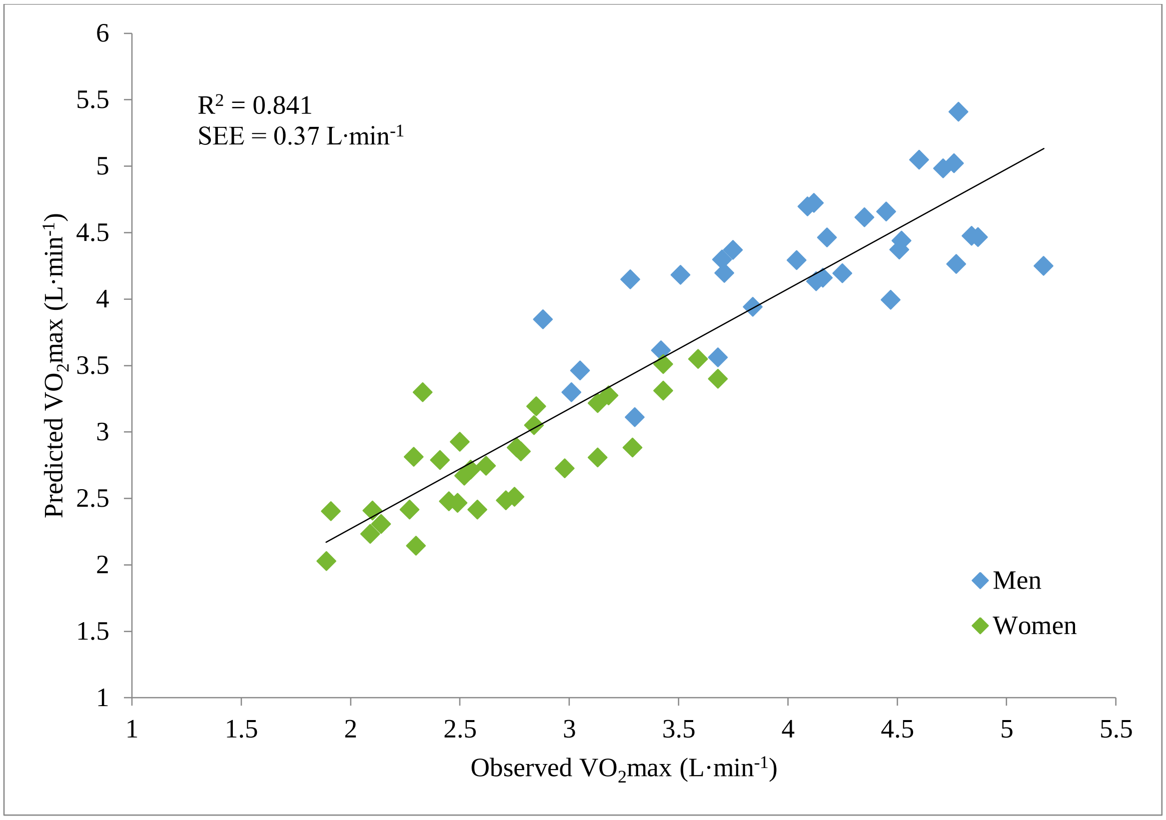

Figure 3. Predicted VO_2max vs. observed VO_2max scatter plot for gender-independent model

Gender specific

Significant predictor variables for the male specific model determined by correlation matrix were height, weight, thigh girth, PP, MP, and FI (Table 5). However, assessment of multicollinearity showed PP and MP were significantly correlated to each other (r = 0.92). Based on previous research (Tanner & Navalta, 2016) MP was excluded due to similar individual correlation between these variables and VO_2max (PP: r = 0.62; MP: r = 0.61). The remaining predictor variables were entered in the regression analysis in the same manner outlined for the gender independent model (Figure 4). Model summary provided in Table 6. Assessment of individual model parameters revealed PP was the only significant contributor to the predictive power of the model. Weight, height, thigh girth, and FI were not significant contributors to the regression model generated:

$\hat{Y} = 2.758 + (0.002 \times PP)$

where PP is measured in watts. A scatter plot of predicted vs. observed VO_2max values for the male specific model is provided in Figure 5. Accuracy determined by SEE and SEE% were 0.49 (L/min) and 11.98% respectively. Validity as determined by comparison of PRESS statistics to R^2 and SEE showed this model is not valid ($R^2 = 0.380$ vs. $R^2_{PRESS} = -0.041382$; SEE = 0.49 vs. $SEE_{PRESS} = 0.61$).

Table 5. Pearson's product-moment correlation for male specific model

Predictor variable	Pearson's r	Significance (*p*-value)
Age (yrs)	-0.32	0.077
Height (cm)	**0.39**	**0.029**
Weight (kg)	**0.36**	**0.04**
Chest skinfold (mm)	-0.04	0.829
Axilla skinfold (mm)	0.14	0.429
Triceps skinfold (mm)	0.04	0.825
Subscapular skinfold (mm)	-0.27	0.134
Abdominal skinfold (mm)	-0.09	0.633
Suprailliac skinfold (mm)	0.01	0.947
Thigh skinfold (mm)	0.05	0.797
Percent body fat	-0.08	0.678
Thigh girth (cm)	**0.41**	**0.021**
Hip girth (cm)	0.29	0.109
RHR (bpm)	-0.18	0.326
PP (W)	**0.62**	**<0.001**
MP (W)	**0.61**	**<0.001**
FI	**0.36**	**0.045**

Note: Pearson's r correlations between VO_2max (L/min) and predictor variables.
Bold values are the significant predictor variables as provided by SPSS

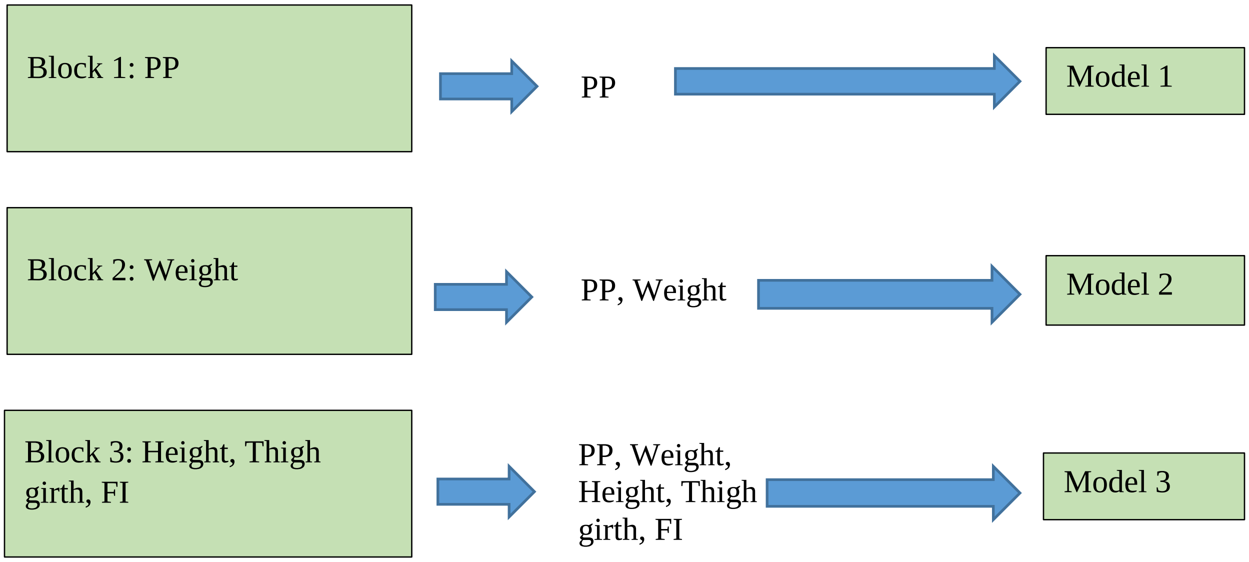

Figure 4. Hierarchical multiple regression variable entry for male specific model

Table 6. Male specific multiple linear regression model summary

Model	R	R^2	Adjusted R^2	SEE
1	0.617[a]	0.380	0.360	0.489
2	0.644[b]	0.415	0.374	0.483
3	0.678[c]	0.460	0.356	0.490

a. Predictors: PP
b. Predictors: PP, weight
c. Predictors: PP, weight, height, thigh girth, FI

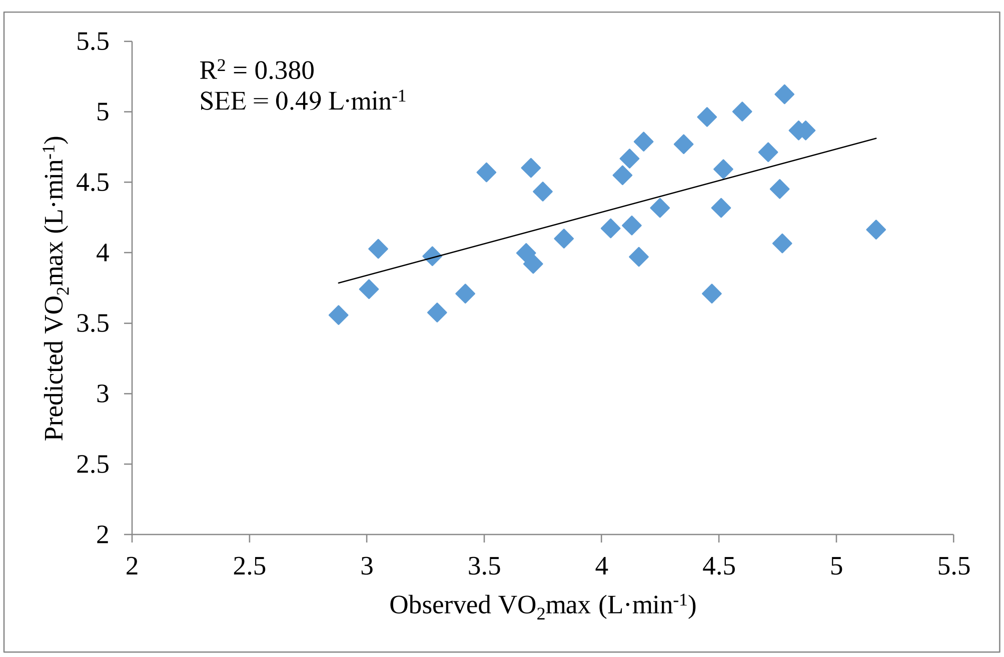

Figure 5. Predicted VO_2max vs. observed VO_2max scatter plot for male specific model

The female specific model involved several different predictor variables in comparison to the gender independent and male specific equations. Based on Pearson's product-moment correlation MP, height, weight, thigh girth, and RHR were significantly correlated to VO_2max (Table 7).

Table 7. Pearson's product-moment correlation for female specific model

Predictor variable	Pearson's r	Significance (*p*-value)
Age (yrs)	-0.16	0.375
Height (cm)	**0.57**	**0.001**
Weight (kg)	**0.60**	**<0.001**
Chest skinfold (mm)	-0.08	0.647
Axilla skinfold (mm)	-0.29	0.106
Triceps skinfold (mm)	-0.08	0.669
Subscapular skinfold (mm)	-0.32	0.073
Abdominal skinfold (mm)	-0.26	0.155
Suprailliac skinfold (mm)	-0.23	0.216
Thigh skinfold (mm)	<0.01	0.995
Percent body fat	-0.22	0.223
Thigh girth (cm)	**0.49**	**0.004**
Hip girth (cm)	0.29	0.105
RHR (bpm)	**-0.48**	**0.006**
PP (W)	0.34	0.057
MP (W)	**0.37**	**0.029**
FI	-0.21	0.259

Note: Pearson's r correlations between VO_2max (L/min) and predictor variables.
Bold values are the significant predictor variables as provided by SPSS

Predictor variable entry followed the same principles as the previous analyzes (Figure 6). Model summary provided in Table 8. The assessment of individual predictor variables revealed the addition of block 2 and block 3 variables (Figure 6) resulted in a non-significant contribution of MP to the prediction of VO_2max. In order to retain an anaerobic power variable model 1, simple linear regression model, was generated:

$$\hat{Y} = 2.061 + (0.002 \times MP)$$

where MP is measured in watts. A scatter plot of predicted vs. observed VO_2max values for the female specific model is provided in Figure 7. Accuracy assessed by SEE and SEE% were 0.45 (L/min) and 16.78% respectively. PRESS statistics showed this model not valid (R^2 = 0.149 vs. R^2_{PRESS} = 0.018; SEE = 0.45 vs. SEE_{PRESS} = 0.50).

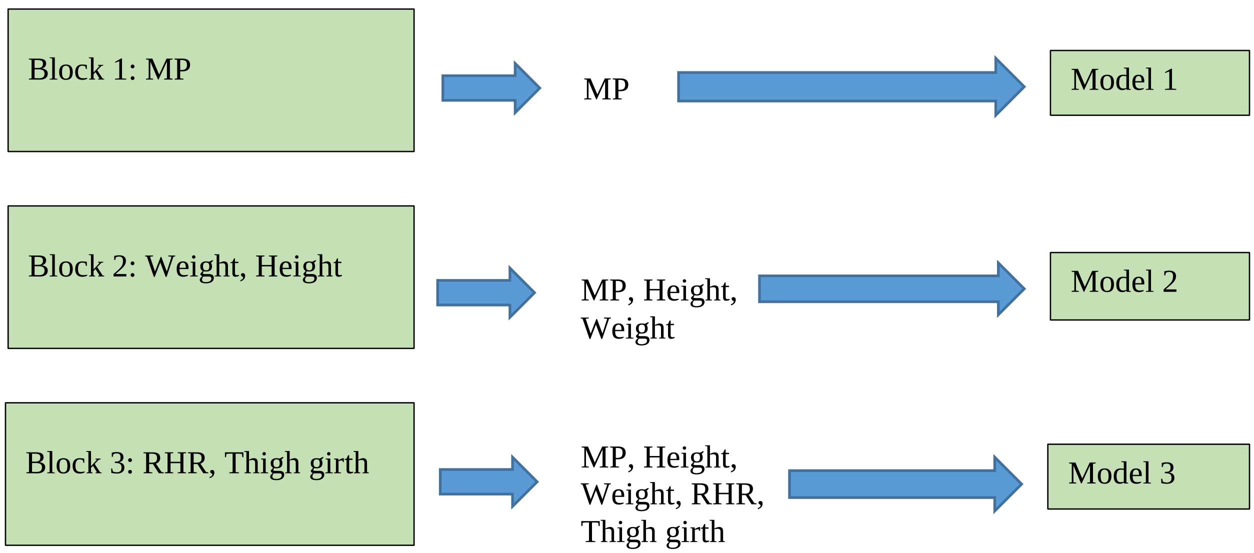

Figure 6. Hierarchical multiple regression variable entry for female specific model

Table 8. Female specific multiple linear regression model summary

Model	R	R^2	Adjusted R^2	SEE
1	0.386[a]	0.149	0.121	0.451
2	0.665[b]	0.443	0.383	0.378
3	0.781[c]	0.610	0.535	0.328

a. Predictors: MP
b. Predictors: MP, weight, height
c. Predictors: MP, weight, height, RHR, thigh girth

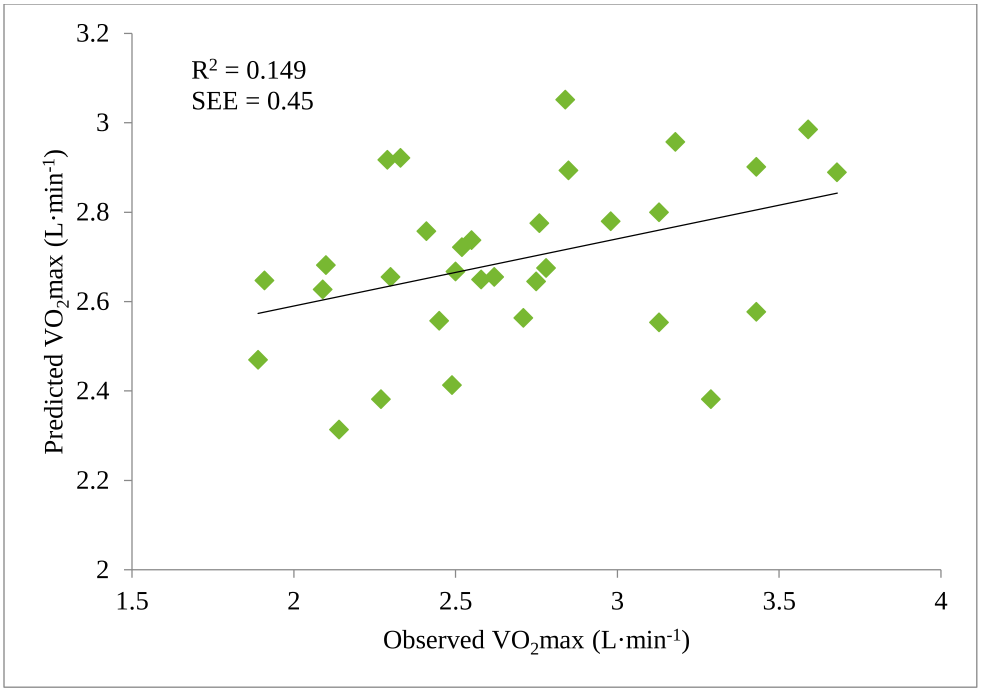

Figure 7. Predicted VO_2max vs. observed VO_2max scatter plot for female specific model

CHAPTER 5

DISCUSSION

The aim of this study was to develop accurate and valid gender independent and gender specific regression models for the prediction of cardiorespiratory fitness from maximal anaerobic power measures. It was hypothesized anaerobic power measures (PP, MP, and FI) from the Wingate cycle test would generate accurate and valid regression models for the prediction of VO_2max utilizing an incremental treadmill protocol. Although these exercise tests were designed to stress different energy pathways (aerobic vs. anaerobic) there is a relationship between anaerobic power output and aerobic performance (Hawley & Noakes, 1992). This connection is facilitated by the predominant energy system at the point of test termination. During the final minutes of an incremental treadmill VO_2max test anaerobic glycolysis is the energy system producing ATP. This system becomes exhausted as exercise intensity increases per the incremental protocol, therefore anaerobic energy pathways permit energy production at intensities in excess of maximal aerobic capacity. Similarly, during the 30 second Wingate cycle test anaerobic energy systems are exhausted at test termination. This bioenergetic similarity suggests power output obtained from the Wingate cycle test along with anthropometric measures can predict VO_2max which is consistent with the results of this study.

The primary predictors for the gender independent prediction model were PP, weight, percent body fat, and RHR. This model produced an R^2 value of 0.841 which indicates the 4 predictors entered in to the model account for 84.1% of the variance in the predicted values for VO_2max. The accuracy of this model as determined by SEE (0.37 L/min) is representative of the variance between predicted and measured VO_2max values. A smaller SEE indicates greater predictive accuracy of the model. The application of this SEE to a reference individual (70 kg) would result in an error in VO_2max prediction of 5.29 ml·kg^{-1}·min^{-1} or 1.5 METs. PRESS-related statistics were chosen to validate the regression models generated in the current study. This method allows issues of estimation bias associated with small sample sizes to be avoided. PRESS modified values of R^2 and SEE are compared to the unmodified forms to assess model validity. A smaller difference between R^2 and R^2_{PRESS} along with SEE and SEE_{PRESS} equates to greater stability or validity of the model. For the gender independent regression model the difference between R^2 and R^2_{PRESS} was small (0.059), likewise the difference between SEE and SEE_{PRESS} was also small (0.046) indicating this model is valid for highly active young men and women.

Unlike the gender independent regression model, the male specific model included PP as the sole predictor variable. Based on the R^2 value for this model, 38% of the variance in predicting VO_2max is explained by PP. SEE indicates this model is accurate to 0.49 L/min which is equivalent to 7 ml·kg^{-1}·min^{-1} or approximately 2 METs in a 70 kg individual. In contrast to the gender-independent model the R^2 and R^2_{PRESS} difference is relatively large (0.421) indicating this model is not valid for highly active young men. This is supported by the comparison of SEE and SEE_{PRESS} (0.124).

The female specific regression model generated in this study is similar to the male specific model. The only predictor variable significantly correlated to VO_2max and a significant contributor to the prediction of VO_2max was MP. Therefore, the regression model specific to females was a simple linear regression model rather than a multiple linear regression model. The R^2 produced for this model showed only 14.9% of the variance in the prediction of VO2max was explained by MP. This result is surprising when compared to the R^2 reported in the pilot study ($R^2 = 0.697$) (Tanner & Navalta, 2016). However, it should be noted that gender selective analysis was not conducted during the pilot study. Although men were included in the pilot study analysis, the drastic reduction of R^2 in the current study warrants further investigation. The accuracy of this model as determined by SEE was 0.45 (L/min) which corresponds to 6.44 $ml \cdot kg^{-1} \cdot min^{-1}$ or approximately 2 METs which is similar to the error in the male specific model. The stability of this model is relatively high with differences of 0.131 and 0.048 respectively in R^2 and SEE compared to the corresponding PRESS modified values.

Comparison of SEE for each regression model generated indicates the gender-independent regression model has the greatest predictive accuracy followed by the female and male specific models. However, the change in SEE between the models is minimal (0.04 - 0.12 L/min) indicating the predictive accuracy of all three models is similar. The hierarchical method of variable entry utilized in the current study also allowed for the gender-independent multiple linear regression model to be compared to the simple linear regression model. The simple linear regression generated from the entire sample (N = 64) reduced the explained variance in predicted VO_2max by almost half ($R^2 = 0.601$) and SEE nearly doubled (SEE = 0.57 L/min). This comparison indicates the gender-independent multiple linear regression model incorporating PP, weight, percent body fat, and RHR has greater predictive accuracy than PP alone.

It is clear based on the result of the current study the gender independent regression model is the most accurate and only valid model generated from this sample of healthy, highly active young adults. To date no other research has attempted to predict VO_2max attained using an incremental treadmill protocol from anaerobic power output from a Wingate cycle test. However, research conducted by Jones and McCartney (1986) and Hawley and Noakes (1992) endeavored to investigate a similar relationship between anaerobic power output and aerobic capacity. Jones and McCartney (1986) successfully correlated the work accomplished during a

30 second cycle test to VO_2max in a sedentary population. A multiple linear regression model was developed with SEE of 0.458 L/min. However, in order to compare regression models developed from different samples SEE% is required. Unfortunately, SEE% was not reported and SEE% could not be calculated from the reported SEE values due to the absence of reported mean VO_2max. Hawley and Noakes (1992) conducted a similar study in trained cyclists. Peak power significantly predicted cycle VO_2max in simple linear regression (SEE = 0.281 L/min). The SEE% was not reported in this study but the mean of the criterion measure (VO_2max) was reported and SEE% could be calculated. The SEE% for the entire sample was 8.22% which indicates a greater predictive accuracy compared to the gender independent regression model generated in the current study (SEE% = 10.89). This may be due to the utilization of the same power and aerobic capacity modality for each exercise test, cycle only, compared to the current study which used two separate modalities, cycle and treadmill. Previous research in the prediction of VO_2max from submaximal treadmill jogging (George, Vehrs, Allsen, Fellingham, & Fisher, 1993) and cycle ergometry (George, Vehrs, Babcock, Etchie, Chinevere, & Fellingham, 2000) follow a similar trend. The prediction of VO_2max from treadmill jogging in college aged adults revealed a SEE% of 6.6% which is much lower than those reported in the current study (gender independent: 10.89%; male specific: 11.98%; female specific: 16.78%). Similarly, a submaximal cycle ergometry protocol designed to predict treadmill VO_2max in healthy young adults reported 7.1 SEE% which is far lower than all the models generated for maximal anaerobic power output prediction of VO_2max utilizing different modalities. The difference in these SEE% values may be accounted for by the difference in sample size (N = 64 vs. N = 156). Another explanation for this difference may be similar usage of aerobic energy production pathways during the exercise tests. In the current study, the Wingate cycle test

stresses the anaerobic energy pathways while the treadmill VO_2max test stress the aerobic pathways for the majority of the exercise test and predominately stresses the anaerobic pathways at the “crossover point” until test termination. It is possible that participants in the current study did not completely exhaust anaerobic energy production pathways to the same degree during both exercise tests which would likely hinder the predictive accuracy in the regression models. The submaximal cycle protocol developed by George and colleagues (2000) likely stressed energy pathways to a similar degree which may have resulted in less predictive error and greater predictive accuracy as indicated by the SEE% reported. An earlier study conducted by George, Stone and Burkett (1997) had similar success in predicting treadmill VO_2max from self-reported non-exercise predictor variables (perceived functional ability, habitual physical activity, and body mass index) in physically active college aged adults. The George et al. (1997) study produced 7.81 SEE% which is considerably more accuracy than the models produced from anaerobic power. However, a similar study conducted by Shenoy and colleagues (2012) predicted treadmill VO_2max from non-exercise data (perceived functional ability, physical activity recall, and body surface area) in college-aged adults revealed a SEE% of 20.77%. Based on these values the models created in the current study appear to be moderately accurate and contribute to the collective knowledge in the area of cardiorespiratory fitness prediction.

The gender-independent model developed for the prediction of treadmill VO_2max from PP obtained using the Wingate cycle test explained a relatively large portion of variance in the criterion measure, 84.1%. This model is moderately accurate and valid. Therefore, application of the gender independent regression model is generalizable to young, highly active young adults. The male specific regression model generated explain relatively small portion of variance in VO_2max at 38%. This model is slight less accurate compared to the gender-independent model

(11.98% vs. 10.89%). However, the model is not stable and it is not advisable to apply the male specific regression model to young, highly active men outside the sample population due to failed validation. The female specific regression model for the prediction of treadmill VO_2max utilized MP as the only predictor variable which accounted for a small amount of variance in the criterion measure, 14.9%. This model is moderately accurate but not valid. The combination of failed validation and low explained variance results in a relatively poor predictive model of cardiorespiratory fitness. This model is not recommended for application in young, highly active women for the prediction of treadmill VO_2max. The accuracy and validity of these models was not assessed in other populations therefore, application in younger or older age groups and low to moderate activity levels is cautioned.

In the future, continued investigations of anaerobic prediction of cardiorespiratory fitness should endeavor to improve the regression models produced in the present study. Specifically, increase the explained variance in VO_2max and decrease the observed error of estimate. This may be accomplished by increasing the sample size. A means to increase sample size may include incorporating the determination of VO_2 plateau (< 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ or 150 $ml \cdot min^{-1}$ increase in VO_2 with an increase in workload) as a VO_2max criteria (Taylor, Buskirk, & Henschel, 1995). This criteria was not included in the currently study due inconsistences of reported VO_2 plateau achievement which have been as low as $\leq$50% of individuals reaching VO_2 plateau during a VO_2max test (Howley et al., 1995). It is likely the addition of more data into the regression analysis will result in previously correlated predictor variables (height, sex, thigh skinfold, triceps skinfold, fatigue index, thigh girth, hip girth) becoming significant contributors to the regression model and increasing the explained variance in VO_2max. The addition of other easily measurable predictor variables absent in the present investigation may also improve the regression model. The current study may have been limited by participant motivation which could lead to disproportionate utilization of anaerobic energy pathways during either/ both exercise tests. This disparity is a possible explanation for the unexplained variance in the current study for each predictive model generated. A potential solution to this limitation includes the development of Wingate cycle test specific criteria for true maximal power attainment. Additionally, anaerobic power measurements specifically peak power could be compared to power achieved at VO_2max to determine whether participants completed each exercise test with similar effort. Implementation of these strategies in future research will likely improve the regression models developed in the current study. The impact of continued predictive research, in particular prediction of VO_2max from anaerobic power, may facilitate the development of regression models that narrow the explained variance in the criterion measure placing this type of regression model comparable to other accurate models as addressed previously. This will allow cardiorespiratory fitness to be applied to a variety of populations or environments in which a measurement of cardiorespiratory fitness through gas analysis is not physically or economically feasible.

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

Department of Kinesiology and Nutrition Sciences

TITLE OF STUDY: Prediction of VO_2max from a single Wingate Test

INVESTIGATOR(S): Dr. James Navalta, Elizabeth Tanner, and Jeffrey Montes

For questions or concerns about the study, you may contact Dr. Navalta at **(702) 895-2344** or Elizabeth Tanner at **(570) 660-8619.**

For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted, contact **the UNLV Office of Research Integrity – Human Subjects at 702-895-2794, toll free at 877-895-2794 or via email at IRB@unlv.edu.**

Purpose of the Study

You are invited to participate in a research study. The purpose of this study is to determine whether results from a 30 second Wingate test (used to assess anaerobic capacity) can be used to predict maximal oxygen consumption, VO_2max which measures aerobic capacity.

Participants

You are being asked to participate in the study because you fit these criteria: between the ages of 18-44 years and classified as low risk for cardiovascular disease. After filling out the Health Risk Questionnaire it is possible that you will not be allowed to participate further in the study. You will be excluded from the study if you are classified as moderate risk or have an implantable device (such as a Pacemaker), or have orthopedic, cardiovascular, respiratory, or metabolic conditions.

Procedures

If you volunteer to participate in this study, you will be asked to do the following: come to the Exercise Physiology Laboratory to complete an incremental treadmill test to achieve VO_2max. Duration ranging from 8-12 minutes, and complete a 30 second Wingate cycle test. There will be a rest period (10-20 minutes) between test protocols in which you will complete a physical activity questionnaire. During the incremental treadmill test, heart rate will be measured by a monitor (a strap that will be placed around your chest), and oxygen consumption will be measured using a gas analysis system connected to a mouthpiece and headgear. We will ask you to perform each test with maximal effort but a test can be terminated at any time if needed. We ask that you come to your test session well rested and well hydrated. We also ask you to refrain from eating 3-4 hours prior to test, engaging in heavy exercise, and consumption of caffeine and alcohol the morning and evening prior to your testing sessions.

Benefits of Participation

There may not be direct benefits to you as a participant in this study, but you will be able to receive free information regarding your measurements from both tests. However, we hope that the results of this study will facilitate the prediction of maximal oxygen consumption, from a single Wingate cycle test.

Risks of Participation

There are risks involved in all research studies. This study may include only minimal risks. The current standard of care, supervision, and preparation will be taken to minimize any hazard or danger. The American College of Sports Medicine has stated that the risk of death during or immediately after a maximal exertion test is less than or equal to 0.01%, while the risk of an acute myocardial infarction is less than or equal to 0.04%. Data from these surveys included a wide variety of healthy AND diseased individuals. Since you are an apparently healthy adult between the ages of 18 - 44 years and are considered “low-risk” according to the American College of Sports Medicine guidelines, no medical supervision is necessary during the exercise test. There may be discomforts associated with the test. Muscle soreness, nausea, breathlessness, dizziness, and lightheadedness may occur. Muscle soreness may ensue 24-48 hours later. The tests will be stopped any time you are not adapting well to the activity or when any major discomfort arises. You will be instructed to grab onto the handrails and straddle the treadmill or stop peddling the cycle when you wish to end the exercise tests. In addition, a research team member will “spot” you from behind during the test.

Cost /Compensation

There may not be financial cost to you to participate in this study. The study will take approximately 45 minutes of your time. You will not be compensated for your time.

Confidentiality

All information gathered in this study will be kept as confidential as possible. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for 3 years after completion of the study. After the storage time, any identifiable information gathered will be destroyed. Unidentifiable data will be stored in locked storage indefinitely.

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with UNLV. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Participant Consent:

I have read the above information and agree to participate in this study. I have been able to ask questions about the research study. I am at least 18 years of age. A copy of this form has been given to me.

Signature of Participant | Date

Participant Name (Please Print)

819974-5, Expiration Date: 09/26/2017

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GENERAL INFORMATION

Education

2015-Present	M.S, *University of Nevada, Las Vegas*, Las Vegas, NV Exercise Physiology
2014-2010	B.S, *Lock Haven University*, Lock Haven, PA Health Science: Pre-Professional Summa Cum Laude Global Honors with Distinction

Teaching Experience

2016-Present	School of Life Sciences Part-time Instructor, University of Nevada, Las Vegas
2015-Present	Exercise Physiology Laboratory Instructor, University of Nevada, Las Vegas

Scholarships & Accomplishments

2016	UNLV James F. Adams/GPSA Scholarship Patricia Sastaunik Scholarship
2014	Athletic Honor Roll PSAC Outdoor Track and Field Qualifier
2013	Karl & Lynne Herrmann Health Science Scholarship Athletic Honor Roll PSAC Outdoor Track and Field Qualifier PSAC Indoor Track and Field Qualifier
2012	Jean B. Robinson Memorial Scholarship Athletic Honor Roll PSAC Outdoor Track and Field Qualifier PSAC Indoor Track and Field Qualifier
2011	Lock Haven University Foundation Scholarship PSAC Indoor Track and Field Qualifier

Grants & Awards

2017	UNLV Graduate & Professional Student Association Grant ($538.87), funded)

	Graduate & Professional Student Association Research Form Outstanding Presentation ($200)
2016	Navalta, JW (PI), Montes J (Co-PI), Bodell, NG (Co-PI), Tanner, EA (Co-PI). Comparison of Walking in Different Environmental Conditions. America Walks Micro Grant ($1500, submitted).
	UNLV Exercise Physiology Travel Award ($100, funded)
	UNLV Graduate & Professional Student Association Grant ($500, funded)
	UNLV Kinesiology & Nutrition Sciences Student Travel Award-Spring ($500, funded)
	GSSI-ACSM Young Scholar Travel Award ($1,000, not funded)
	Charles M. Tipton Student Research Award ($1,200, not funded)
	Michael L. Pollock Student Scholarship ($200, not funded)
2015	UNLV Exercise Physiology Travel Award ($80.00, funded)
	UNLV Foundation Student Travel Award ($1,500, not funded)
2014	Second Highest Academic Achievement in the College of Natural, Behavioral, and Health Sciences Award
	Pennsylvania State Athletic Conference Scholar-Athlete Award
2013	Pennsylvania State Athletic Conference Scholar-Athlete Award
2012	Pennsylvania State Athletic Conference Scholar-Athlete Award
	Lock Haven Track and Field Coaches Award
2011	Pennsylvania State Athletic Conference Scholar-Athlete Award
	Lock Haven Track and Field Women's Thrower Award
2010	Pennsylvania State Athletic Conference Scholar-Athlete Award

Certifications

American Heart Association: CPR and AED certified

Memberships

American College of Sports Medicine
Southwest American College of Sports Medicine

RESEARCH

Manuscripts

Tanner, E.A, Montes, J., Manning, J.W., Taylor, J., DeBeliso, M., Young, J.C., Navalta, J.W. (2016): Validation of Hexoskin Biometric Shirt to COSMED K4 b^2 Metabolic Unit in Adults During Trail Running, Sports Technology, DOI:10.1080/19346182.2016.1248973.

Professional Presentations and Refereed Published Abstracts

Tanner, E.A., Navalta, J.W. Prediction of Cardiorespiratory Fitness from Maximal Anaerobic Capacity in Young Adults: A Pilot Study. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Bodell, N.G., Tanner, E., Montes, J., MacDonald, G.A., Thomas, C., Manning, J.W., Taylor, J.E., Navalta, J.W. Excess Post-exercise Oxygen Consumption Following Bouts of Moderate and Vigorous Climbing. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Aguilar, C.D., Woita, A.C., Montes, J., Bodell, N.G., Tanner, E.A., MacDonald, G.A., Thomas, C., Manning, J.W., Taylor, J., Navalta, J.W. Prediction of Mechanical Efficiency from Body Fat Percentage and Years of Experience in Male and Female Rock Climbers. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

MacDonald, G.A., Montes, J., Tanner, E.A., Bodell, N.G., Manning, J.W., Navalta, J.W. A Mile Trail Run can Predict Performance for a 5K Trail Race. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Navalta, J.W. Montes, J., Tanner, E.A., Bodell, N.G., Young, J.C. Sex and Age Differences in Trail Half Marathon Running. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Tallent, R.C., Woita, A.C., Aguilar, C.D., Young, J., Navalta, J.W., Bodell, N.G., Montes, J., Tanner, E.A., MacDonald, G.A., Thomas, C., Manning, J.W., Taylor, J. Comparison of Mechanical Efficiencies from Steady State and Rapid Speed Rock Climbs. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Woita, A.C., Young, J., Navalta, J.W., Bodell, N.G., Montes, J., Tanner, E.A., MacDonald, G.A., Thomas, C., Manning, J.W., Taylor, J. Mechanical Efficiency during Repeated Attempts of Indoor Rock Climbing. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2016.

Tanner, E., Manning, J.W., Taylor, J., Montes, J., McCune, D., Koschel, T.L., Tacad, D.K., Tovar, A., Young, J.C., DeBeliso, M., Navalta, J.W. Validation of Hexoskin Biometric Shirt to Cosmed $K4b^2$ Metabolic Unit in Adults During Trail Running. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2015. Also presented at the Annual Meeting of the American College of Sports Medicine, Boston, MA. *Medicine and Science in Sports and Exercise*, 48(5): S461, 2016.

Tacad, D.K., Manning, J.W., Montes, J., Tanner, E., McCune, D., Koschel, T., Tovar, A., Taylor, J., Navalta, J.W., DeBeliso, M., Young, J.C. Post Exercise Hypotension Response in Non-Hypertensive Adults Following a Self-paced Trail Run. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2015. Also presented at the Annual Meeting of the American College of Sports Medicine, Boston, MA. *Medicine and Science in Sports and Exercise*, 48(5): S361, 2016.

Koschel, T.L., Manning, J.W., Tacad, D.K., Montes, J., Tanner, E., McCune, D., Tovar, A., Taylor, J., Young, J.C., DeBeliso, M., Navalta, J.W. Moderate Altitude Acclimation has no Effect on Respiratory Exchange Ratio, or Percent of CHO and Fat Utilization During a 1-Mile Trail Run. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2015. Also presented at the Annual Meeting of the American College of Sports Medicine, Boston, MA. *Medicine and Science in Sports and Exercise*, 48(5): S1027, 2016.

Navalta, J.W., Manning J.W., Tacad, D.K., Montes, J., Tanner, E., McCune, D., Koschel, T.L., Tovar, A., Taylor, J., Young, J.C., DeBeliso, M. Body Mass Index has no Effect on the Post

Exercise Hypotension Response Following a Trail Run. Annual Meeting of the Southwest American College of Sports Medicine, Costa Mesa, CA, 2015.

TEACHING

University of Nevada, Las Vegas

2016-Present Anatomy and Physiology I Laboratory
2015-Present Exercise Physiology Laboratory

SERVICE

Editorial Board

2015-Present International Journal of Exercise Science (Student Managing Editor)

Community

2017 Rebel Relay
2012-2014 Relay for Life

University of Nevada, Las Vegas

2015 Rebel Service Day

Lock Haven University

2012-2014 NCAA Division II Atlantic Region XC Championships
2011-2014 LHU High School Invitational
LHU High School Classic
2010-2013 XC Bear Mountain Run
Homecoming 5k
Go Fast River Run
Dolan Duals

Other Work Experience

2016-Present UNLV-School of Life Sciences Part Time Instructor
Responsibilities: Instruct undergraduate anatomy and physiology I laboratories. Evaluate undergraduate students in varied allied health science disciplines on practical and theoretical knowledge of anatomy and physiology.

2015-Present UNLV-Kinesiology and Nutrition Sciences Graduate Assistant
Responsibilities: Instruct undergraduate exercise physiology laboratories. Assist with current research projects conducted in the exercise physiology laboratory. Assist with various physical fitness assessments in athletic, university, and community populations conducted in the exercise physiology laboratory.

2014-2015 Humboldt General Hospital-Admitting and Emergency Room Receptionist
Responsibilities: Direct patient inquires and execute patient payments. Admit patients for medical services. Provide medical records for onsite and offsite

medical professionals. Organize hospital to hospital transport and assist in various capacities during medical emergencies.

2013-2014 LHU-Exercise Physiology Laboratory Volunteer Assistant
Responsibilities: Assisted with current research projects and community fitness program assessments conducted in the exercise physiology laboratory. Executed various physical fitness measurements and recorded participant data. Participated in various research projects.

Summer 2013 Humboldt General Hospital-Wellness/ Cardiac Rehabilitation Volunteer
Responsibilities: Organized and filed patient records. Provided feedback for program development and community speaker series. Attended various community events sponsored by Humboldt General Hospital.

Summer 2013 Rehab Services of Nevada-Physical Therapy Volunteer
Responsibilities: Provided various patient modalities and equipment maintenance. Recorded patient rehabilitation program progression and assessment results. Directed patient inquires.

2011-2014 LHU-Track and Field Department Student Assistant
Responsibilities: Executed various office tasks and transported items throughout campus. Assisted in the organization and execution of collegiate and high school athletic events. Supervised various student athlete educational events.

2011-2012 LHU-Department of Athletics Student Assistant
Responsibilities: Transported various items throughout campus. Prepared fall and spring fundraising raffles and directed customer service inquires.

REFERENCES

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