Keystone Journal of Undergraduate Research 4(1): 49-55. 2017

Comparison of Estimated Aerobic Power to Measured Aerobic Power in Aerobically Trained Athletes

Lucas Van Horn, Matthew Cuomo, Shane Huntbach, Alicia O'Donel, and Chris Mullins

Dr. William A. Braun

Department of Exercise Science
Shippensburg University

ABSTRACT

The Astrand protocol estimates aerobic power (VO_{2max}) using leg ergometry. This study was designed to determine how accurately the Astrand submaximal protocol estimates the measured VO_{2max} in aerobically trained athletes. Eleven aerobically trained athletes (6 male and 5 female) who exercised 300+ min/wk participated in the study (age 21.36 ± 2.38yr, height 67.96 ± 2.31in, and mass 63.79 ± 8.97kg). Subjects were tested on two protocols: 1) estimation of aerobic power using a modified Astrand test and 2) determination of aerobic power via indirect calorimetry. Both tests were performed using cycle ergometry at a fixed cadence (70 RPM) with the submaximal protocol maintaining a constant workload while the measured VO_{2max} test used graded exercise. Heart rate and RPE (rating of perceived exertion) were collected throughout both protocols. There was no significant difference ($p \geq 0.05$) between the Astrand predicted (57.6 ± 8.4 $ml \cdot kg^{-1} min^{-1}$) and the measured VO_{2max} (50.05 ± 8.6 $ml \cdot kg^{-1} min^{-1}$). The Pearson correlation between the predicted and measured VO_{2max} was $r = 0.794$ (p=0.089), indicating a moderate to strong relationship between the two variables. Based on the results of this study, there was no statistical difference between the submaximal aerobic prediction and the measured VO_{2max}. This indicates that the submaximal aerobic protocol effectively predicts the aerobic power in aerobically trained individuals.

Keywords: VO_{2max}; Cardiorespiratory Fitness; Endurance; Leg Ergometry

INTRODUCTION

The cardiovascular and respiratory systems determine the capacity at which the body can perform vigorous amounts of work. These two systems combine to dictate how much oxygen can be transported and taken up by the muscles in order to continue working at a high level. The ability to measure the maximum oxygen uptake is useful when determining the capacity of the cardiovascular system to fuel the body's need for oxygen during exercise (Dotson et. al., 1984).

The accurate measurement of maximal oxygen uptake is important when trying to determine the aerobic fitness level of endurance athletes. A higher VO_{2max} can allow them to work more efficiently through their training (Miller et. al., 2007). The VO_{2max} can adapt and will be influenced by physiological variables as an individual increases their aerobic capacity through exercise training. The heart will adapt and increase its stroke volume while lowering the resting heart rate. This allows the heart to work more efficiently when pumping blood throughout the body with less stress. The lungs will also undergo change by increasing the tidal volume taken in with each breath, allowing for more oxygen to be supplied to the hemoglobin within the blood through the alveolar sacs (Miller et. al., 2007).

When examining VO_2 within an athlete, there are many ways to directly test and estimate the amount of oxygen consumed per minute. Two of the most common ways to assess the VO_{2max} are by estimation with the aerobic submaximal protocol that are based on the relationship with heart rate, or testing the relationship between work rates using indirect calorimetry. The Astrand submaximal prediction utilizes the measurement of heart rate in order to estimate VO_2 based on a submaximal rate of work. This correlation of oxygen consumption and heart rate was assumed to be linear, thus eliciting the possibility of measuring heart rate to predict VO_2 (Dotson et. al., 1984). A GXT puts a subject through a series of incremental stages of an increasing workload, while monitoring their heart rate and expelled gases using a gas analyzer, over the course of the exercise protocol. While the metabolic cart enables determination of an individual's oxygen uptake, the Astrand protocol has been widely used to estimate the VO_{2max} in the general population. This test is less invasive, is submaximal, and is performed with common laboratory equipment.

The Astrand protocol gives boundaries for where to fix the workload for trained athletes, but it doesn't appear to accurately predict the VO_{2max} of an aerobic athlete. In some populations, the fixed workloads do not seem to provide sufficient measures of resistance in order to elicit a heart rate response that can be used within the test nomogram to predict the VO_{2max}. Astrand predictions of VO_{2max} have been shown to underestimate the true VO_{2max} of the individual (Hoehn et. al., 2015). There is also weak validity for the aerobic submaximal VO_2 protocol based upon the predictive values calculated by the Astrand nomogram. As shown in the study by Nielson (2009), within a realm of college-aged students the submaximal aerobic test yielded relatively accurate VO_{2max} estimates, but the estimates tended to overestimate VO_{2max} in those with an overall lower resting heart rate (Nielson 2009). Consequently, the Astrand test may not be suitable for use amongst highly trained endurance athletes, due to their lower resting HRs and lower submaximal HR response. If a large percentage of error between the submaximal aerobic prediction and a measured VO_{2max} is found, it may be appropriate to develop a separate coefficient for use with those who are highly trained.

The purpose of this study was to evaluate the effectiveness of the Astrand protocol at predicting a measured VO_{2max} in an aerobically trained population. It is hypothesized that the Astrand submaximal prediction would over estimate the VO_{2max} for this population, based on the preexisting physiological adaptations due to extensive aerobic training. Furthermore, the study was aimed to establish an overall understanding of estimated and actual VO_{2max} correlations, as well as whether or not the aerobic prediction protocol would consistently over or under predict aerobic power.

METHODS

Subjects

Eleven aerobically trained individuals (six males and five females: age 21.36 ± 2.38yr, height 67.96 ± 2.31in, and mass 63.79 ± 8.97kg), volunteered to participate in the study. Each individual trained at least five days per week for sixty or more minutes per session or three hundred plus minutes of weekly aerobic activity. Subjects were recruited by word of mouth and through email. Emails were sent to coaches of aerobically based sports teams at the university, requesting for the coach's permission to allow their athletes to participate in the experiment. The

Shippensburg University Research IRB approved this study before testing began.

Experimental Protocol

Day 1. Subjects came to the laboratory and were given a Physical Activity Readiness Questionnaire (PAR-Q), as well as an informed consent document to fill out that informed them of the possible risks and benefits involved with participating in the study. On the same visit, after obtaining informed consent, they completed a familiarization trial for the submaximal testing protocol that allowed them to become accustomed to the Monark 828e ergometer (Monark Exercise AB, Vansbro, Sweden), the Parvo Medics TrueOne 2400 (Parvo Medics, East Sandy, Utah, USA) metabolic measurement system, heart rate monitor, blood pressure cuff, and mouthpiece and nose clip. Height, weight, baseline heart rate, blood pressure, and ergometer seat height were also measured for future reference. Participants were informed of the guidelines that had to be followed prior to each testing protocol. These guidelines included: No caffeine or nicotine as well as no eating or drinking with the exception of water two hours prior to the test. Exercise was to be avoided for twenty-four hours prior to the testing protocols. Participants were required to wear free and non-restrictive clothing including t-shirts, shorts, and athletic footwear.

Day 2. Prior to starting the submaximal testing protocol the subjects were placed in a neutral environment with limited distractions for 15 minutes. This allowed for the collection of baseline heart rate and blood pressure measurements without external influence. Then the subjects warmed up on an electronically braked ergometer at a low wattage for three minutes. The subjects then started with the six-minute submaximal testing protocol. During this protocol, the wattage was set at 125W and each subject cycled at a rate of 70rpm for all six minutes. At the end of each minute, HR and RPE were recorded and blood pressure was obtained at the end of minute three and six. This concluded the testing protocol after which, the subjects completed a three-minute cool down to promote recovery.

Day 3. Prior to starting the VO_{2max} testing protocol each subject was instructed to relax in a quiet environment with limited distractions. This facilitated the collection of baseline heart rate and blood pressure measurements. Testing was conducted using a calibrated ParvoMedics TrueOne metabolic measurement system (ParvoMedics, Sandy UT). The subject was equipped with a mouthpiece and nose clip and instructed to breathe at rest until expired gas concentration stabilized. Data collection then commenced.

During stage one of the VO_{2max} testing protocol, the subjects began cycling at 75W at a constant speed of 70rpms for two minutes. The power was increased by 50W for the next two stages; with each stage lasting two minutes. Every consecutive stage thereafter was increased by 25W until volitional fatigue was achieved. At the end of each stage, metabolic data and RPE were recorded. Heart rate was collected by a Polar H1 heart rate sensor (Polar Electro Inc., Lake Success, NY) and a Polar RS100 watch. If the subject failed to complete any stage at the required 70rpm or upon request of stopping by the participant; the testing protocol was terminated. Following the completion of the final stage, subjects were required to complete a cool down for three minutes, to promote recovery. Expired gases were analyzed for rate of oxygen uptake, respiratory exchange ratio (RER) and ventilatory volume.

RESULTS

Subheading

After the testing was completed, the $VO2_{max}$ data (measured vs. predicted) were analyzed using a paired samples t-test (SPSS Inc., Chicago, IL). As shown in Table 1, for the 11 participants, the average submaximal predicted VO_{2max} was 57.6±8.37 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. The average measured VO_{2max} was 50.05±8.62 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. Utilizing a paired sample T-test, a critical p-value of 0.05 was established. There was no statistical significance recorded between the submaximal predicted and the measured VO_{2max} ($p=0.089$). The Pearson correlation value between the submaximal predicted and the measured VO_{2max} was 0.794. Therefore, a moderate to strong linear relationship was found between the submaximal predicted and the measured VO_{2max}. As shown by Table 1, the average heart rate attained during the submaximal predicted protocol was 144bpm, while the measured VO_{2max} average heart rate was 177bpm. RPE was not recorded for the submaximal test, but the average RPE reached for the GXT was 17.7.

Table 1. Averages of Astrand (Predicted) and Measured VO_{2max} Test measurements.

Summary Data Table		
Measurement	Astrand (Predicted)	Measured VO_{2max} Test
Heart Rate	144.1	177.6
VO_{2max} (L/min)	3.7	3.2
VO_{2max} ($ml{\bullet}kg^{-1}{\bullet}min^{-1}$)	57.6	50.1
RPE	X	17.7

In order to gauge predictive test quality by sex, male and female test results were also analyzed independently. As Table 2 portrays, the Astrand test HR for the males was 134.2 bpm, while the females' was 156 bpm. For the VO_{2max} test, the males registered a 183.3 bpm heart rate, while the females achieved an average peak HR of 170.6 bpm. The Astrand predicted VO_{2max} for the males was 56.58 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, while the females' predicted VO_{2max} was 58.83 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. For the VO_{2max} test, the males registered a 56.32 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, while the females' VO_{2max} was recorded to be 42.54 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. The analysis of the two values indicates that the submaximal protocol overestimated the oxygen uptake for the female sample by 38.35% compared to the measured VO_{2max}. Peak RPE for the males for the VO_{2max} test was 18.5, while the females' was 16.8. End stage reached by 2-minute intervals on average was 9 (i.e. 325 W) for the males and 5.6 (225-250 W) for the females. Figure 1, also shows the comparison between the Astrand predicted and measured VO_{2max} for both sexes.

Table 2. Sex differences between Astrand (Predicted) and Measured VO_{2max} Test measurements.

Split Gender Data Table				
Gender	Males		Females	
Measurement	Astrand (Predicted)	Measured VO_{2max} Test	Astrand (Predicted)	Measured VO_{2max} Test
Heart Rate (bpm)	134.2	183.3	156	170.6
VO_{2max} (L/min)	3.9	3.9	3.6	2.4
VO_{2max} ($ml{\bullet}kg^{-1}{\bullet}min^{-1}$)	56.6	56.3	58.8	42.5
RPE for Max Test	18.5		16.8	
End Stage Reached	9		5.6	

DISCUSSION

Based on the results of this study, there was a moderate to strong correlation between the Astrand predicted VO_{2max} and the VO_{2max} derived from the indirect calorimetry in well-trained young adults. This means that the submaximal method does seem to follow a relatively strong relationship to the GXT derived VO_{2max} in a well-trained aerobic population. When evaluating the results based on sex, the submaximal prediction depicts that the predicted values for males and females were very similar for VO_{2max} (male = 56.58 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$and female = 58.83 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). Although these values indicate that overall the two groups were relatively close, it was shown during testing that the males were able to achieve much higher VO_{2max} values (56.32 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) than the female subjects (42.54 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). This can be compared to a study by Cink et al. (1981), who conducted a study on 40 individuals that focused on three levels of trained males (untrained, moderately trained, and well trained). They found that there was no significant difference between the predicted VO_{2max} values and the measured VO_{2max} values, which is similar to our male subject data as described in Table 2. A comparison study by Hoehn et al. (2015) also showed, when split for gender, the Astrand indicated no difference in female subjects, but it under-estimated the male values by a slight margin. This study was similar to the current study but the results conflict with our outcomes for predictive accuracy in females.

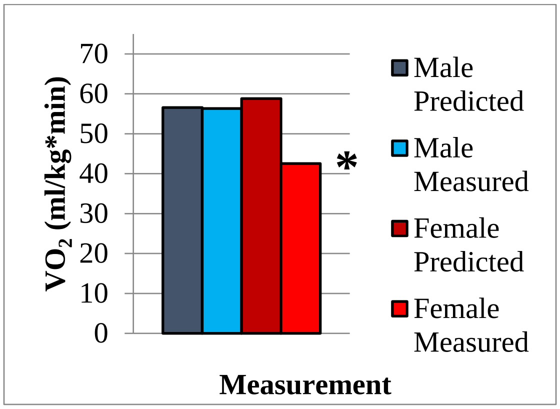

Figure 1. Sex differences for VO_{2max} for the Astrand (Predicted) and Measured VO_{2max} Tests. * = Different from Female estimated VO_{2max}.

It is not uncommon for predictive tests to vary in validity when contrasted against a standard measure. Dolgener et al. (1994) evaluated the predictive accuracy of the Rockport Fitness Walking Test (RFWT) in a college population. They found that in this population, the predictive equation for estimating aerobic power from the RFWT over-predicted VO2max by a range of 16-23%. Thus, for this test, it was deemed that a separate equation should be developed for estimating VO_{2max} from the RFWT in college-aged populations (Dolgener et al., 1994). Ultimately, the predictive quality of an aerobic power test may regularly be dependent upon the population that is being screened.

Previously, Rexhepi and Brestovci (2011) utilized the Astrand submaximal test and based the workloads off of the participant's age and fitness level. They compared a submaximal bike test (3' diameter wheel) against the Astrand cycle ergometer test. Similar workloads were used for all of the 1,492 subjects tested. Rexhepi and his colleagues (2011) found that the Astrand submaximal test was a better predictor of maximum heart rate and VO_{2max} than the 3' Bike Test. The 3' Bike Test showed a lower percentage of predicted maximal heart rate compared to the Astrand submaximal test. The time to obtain a heart rate within the acceptable range for prediction (based on the Astrand nomogram) for the 3' bike test (3 mins.) was lower overall than the Astrand test (5 mins.). The Astrand submaximal test was shown to be more efficient at achieving a more accurate predictive maximal heart rate even though it took more time. This generalization incurs that the Astrand submaximal protocol can elicit a better overall response across a wider population to determine VO_{2max} (Rexhepi et. al., 2011). This indicates that the submaximal prediction can calculate oxygen uptake for a generalized population more accurately and consistently, similar to the results concluded in our study for our population as a whole.

While the cycle ergometer test is maintained at a regular pace and workload, individuals could vary from pace and workload, as shown by Faulkner et al. (2015). They compared VO_{2max} derived from a graded exercise test and compared this to a self-paced VO_{2max} test on a treadmill. The experimenters were looking to see the differences between self-paced incrementally staged tests that were similar to that of a measured VO_{2max} test. It was found that the self-paced test elicited a higher VO_{2max}; however, the GXT VO_2 response was statistically more significant when correlating heart rate to VO_2 measures (Faulkner et. al., 2015). This is important to consider when using the linear relationship between these two physiological measures to determine

VO_{2max}. Our study mirrored this logic when determining the values for rpm and workload increments, in order to elicit a linear response from the endurance athlete subject pool.

As with any study, this research study encountered a few obstacles over the course of the experiment. When comparing the VO_{2max} values as a whole, the conclusion was that they were similar; but, when examining them based on sex, this was not the case. For the measured VO_{2max} test, the males were able to elicit a higher work rate than the females, eliciting higher VO_{2max} values which were much closer to their predicted VO_{2max} values, as compared to the females who fell short of the Astrand predicted VO_{2max}, presumably as a result of premature fatigue (Table 2). During pilot data testing, the initial GXT work rate appeared to be too intense. So, after deliberation, the initial stage work rate was reduced to reduce the risk of premature fatigue. But, as the testing showed, for the measured VO_{2max} test the stages were still quite challenging for the female population and this appears to have led to premature fatigue during VO_{2max} testing. The second two stages (50 W increments) appear to have been too aggressive. The highest wattage that was recorded for the female subjects fell between 225-250 W, while the highest male resistance was 325 W. This limitation is one that could be corrected in order to better achieve the VO_{2max} for both sexes. This also brings up the point of the competitive nature of the athlete to be able to push through the discomfort and totally exhaust the subjects. A noticeable distinction in genders could be the tolerances to lactic acid build up within the muscles during vigorous exercise. With a lower tolerance to the lactic acid, the participants would have felt more pain and soreness, thus resulting in termination of the protocol at an earlier stage. The type and intensity of training that participants perform could be a limiting factor as well. Those who train at a more vigorous aerobic capacity would be more experienced with exposure to lactic acid production and hyperventilation vs. those those who train at a lighter more comfortable level. The participants of the study were primarily endurance runners (none were trained cyclists). Thus, even mode could be a factor in development of premature fatigue. Though, it would be presumed that fatigue resulting from a novel mode of exercise would affect both sexes in the same fashion. In order to achieve the necessary level of focus and determination, motivation would have had to have been high in order to push through the experimental protocol.

CONCLUSION

The results of this study showed that the submaximal prediction of the VO_{2max}, as derived using the Astrand nomogram and age correction, accurately estimated the VO_{2max}, as measured by indirect calorimetry, in aerobically trained individuals. However, when reviewing the data based on sex, there were differences in predictive accuracy. The Astrand test over-predicted the measured VO_{2max} in the females by 38.4%. However, given that the females achieved only 85.6% of HR_{max}, it appears that the measured VO_{2max} may have represented underperformance. This result could be reflective of the training status of the participants, as well as the understanding that some of the individuals should have been tested at a lower resistance level at first, with the resistance building more gradually. Furthermore, it should be explained to the participants during the measured VO_{2max} test, that the participants should continue until fully exhausted, pushing themselves to fatigue, instead of potentially terminating the test as soon as discomfort sets in. More encouragement or greater motivation may have led to better agreement between the two tests in female participants. Maximal aerobic power determination is limited by numerous factors, including intrinsic motivation. The results of this study indicate, though, that predictive aerobic power tests can be validly applied to well-trained aerobic athletes. Further, the results may raise awareness of limiting factors when conducting graded exercise testing to fatigue. The sex-based outcomes of this study may lend additional insight on strategies to consider when measuring aerobic power using a novel mode in trained populations.

LITERATURE CITED

Cink RE, Thomas TR. (1981). Validity of Astrand- Ryhming nomogram for predicting maximal oxygen intake. *Brit J Sports Med* 15: 182-185.

Dolgener, F.A., Hensley, L.D., Marsh, J.J., Fielstul, J.K. (1994) Validation of the Rockport Fitness Walking Test in college males and females. *Res Q Exerc Sport* 65(2): 152-158.

Dotson, C., & Caprarola, M. (1984). Maximal oxygen intake estimated from submaximal heart rate. *Brit J Sports Med 18*(3), 191-194.

Hoehn, A. M., Mullenbach, M. J., & Fountaine, C. J. (2015). Actual Versus Predicted Cardiovascular Demands in Submaximal Cycle Ergometer Testing. *Int J Ex Sci 8*(1), 4-10.

Faulkner, J., Mauger, A., Woolley, B., & Lambrick, D. (2015). The efficacy of a self-paced VO2max test during motorized treadmill exercise. *Int J Sports Physiol Perform*, 10 (1), 99-105.

Miller, G., Dougherty, P., Green, J., & Crouse, S. (2007). Comparison of cardio respiratory responses of moderately trained men and women using two different treadmill protocols. *J Strength Cond Res*, 21(4), 1067-1071.

Nielson, David E. (2009). Predicting VO_{2max} in college-aged participants using cycle ergometry and nonexercise measures. *Meas Phys Educ Exerc Sci*, 14: 252-264.

Rexhepi, A., & Brestovci, B. (2011). Comparison of the 3' bike test with the astrand bike test by VO_{2max}. *Human Movement*, 12(4), 348-352.