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

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ABSTRACT

The Astrand protocol estimates aerobic power (VO2max) using leg ergometry. This study was designed to determine how accurately the Astrand submaximal protocol estimates the measured VO2max 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 VO2max test used graded exercise. Heart rate and RPE (rating of perceived exertion) were collected throughout both protocols. There was no significant difference (p ≥ 0.05) between the Astrand predicted (57.6±8.4 ml·kg⁻¹·min⁻¹) and the measured VO2max (50.05±8.6 ml·kg⁻¹·min⁻¹). The Pearson correlation between the predicted and measured VO2max 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 VO2max. This indicates that the submaximal aerobic protocol effectively predicts the aerobic power in aerobically trained individuals.

Keywords: VO2max; 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 VO2max can allow them to work more efficiently through their training (Miller et. al., 2007). The VO2max 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 VO2 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 VO2max 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 VO2 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 VO2 (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 VO2max 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 VO2max 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 VO2max. Astrand predictions of VO2max have been shown to underestimate the true VO2max of the individual (Hoehn et. al., 2015). There is also weak validity for the aerobic submaximal VO2 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 VO2max estimates, but the estimates tended to overestimate VO2max 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 VO2max 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 VO2max in an aerobically trained population. It is hypothesized that the Astrand submaximal prediction would over estimate the VO2max 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 VO2max 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$_{2\text{max}}$ 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$_{2\text{max}}$ testing protocol, the subjects began cycling at 75W at a constant speed of 70rpm 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**
After the testing was completed, the VO$_{2max}$ 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 $57.6 \pm 8.37$ ml·kg$^{-1}$·min$^{-1}$. The average measured VO$_{2max}$ was $50.05 \pm 8.62$ ml·kg$^{-1}$·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. |
|---------------------------------|---------------------------------|--------------------------------|--------------------------------|
|                                | Heart Rate                      | VO$_{2max}$ (L/min)           | VO$_{2max}$ (ml·kg$^{-1}$·min$^{-1}$) |
| Measurement                   | Astrand (Predicted)            | Measured VO$_{2max}$ Test     |                                   |
| Heart Rate                    | 144.1                           | 177.6                         |                                   |
| VO$_{2max}$ (L/min)           | 3.7                             | 3.2                           |                                   |
| VO$_{2max}$ (ml·kg$^{-1}$·min$^{-1}$) | 57.6                           | 50.1                          |                                   |
| RPE                           | X                               |                               |                                   |

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·kg$^{-1}$·min$^{-1}$, while the females’ predicted VO$_{2max}$ was $58.83$ ml·kg$^{-1}$·min$^{-1}$. For the VO$_{2max}$ test, the males registered a $56.32$ ml·kg$^{-1}$·min$^{-1}$, while the females’ VO$_{2max}$ was recorded to be $42.54$ ml·kg$^{-1}$·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.

**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·kg$^{-1}$·min$^{-1}$and female = $58.83$ ml·kg$^{-1}$·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·kg$^{-1}$·min$^{-1}$) than the female subjects ($42.54$ ml·kg$^{-1}$·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 \( \text{VO}_{2\text{max}} \) values and the measured \( \text{VO}_{2\text{max}} \) 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 \( \text{VO}_{2\text{max}} \) for the Astrand (Predicted) and Measured \( \text{VO}_{2\text{max}} \) Tests. * = Different from Female estimated \( \text{VO}_{2\text{max}} \)](image)

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 \( \text{VO}_{2\text{max}} \) by a range of 16-23\%. Thus, for this test, it was deemed that a separate equation should be developed for estimating \( \text{VO}_{2\text{max}} \) 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 \( \text{VO}_{2\text{max}} \) 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 \( \text{VO}_{2\text{max}} \) (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 \( \text{VO}_{2\text{max}} \) derived from a graded exercise test and compared this to a self-paced \( \text{VO}_{2\text{max}} \) 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 \( \text{VO}_{2\text{max}} \) test. It was found that the self-paced test elicited a higher \( \text{VO}_{2\text{max}} \); however, the GXT VO₂ response was statistically more significant when correlating heart rate to VO₂ measures (Faulkner et. al., 2015). This is important to consider when using the linear relationship between these two physiological measures to determine
VO$_{2\text{max}}$. 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$_{2\text{max}}$ 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$_{2\text{max}}$ test, the males were able to elicit a higher work rate than the females, eliciting higher VO$_{2\text{max}}$ values which were much closer to their predicted VO$_{2\text{max}}$ values, as compared to the females who fell short of the Astrand predicted VO$_{2\text{max}}$, 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$_{2\text{max}}$ test the stages were still quite challenging for the female population and this appears to have led to premature fatigue during VO$_{2\text{max}}$ 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$_{2\text{max}}$ 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 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$_{2\text{max}}$, as derived using the Astrand nomogram and age correction, accurately estimated the VO$_{2\text{max}}$, 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$_{2\text{max}}$ in the females by 38.4%. However, given that the females achieved only 85.6% of HR$_{\text{max}}$, it appears that the measured VO$_{2\text{max}}$ 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$_{2\text{max}}$ 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


