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Examination of current VO2max criteria and the necessity of a verification phase following a maximal incremental ramp test to confirm VO2max

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Examination of current VO_2max criteria and the necessity of a verification phase following a maximal incremental ramp test to confirm VO_2max

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the thesis of

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ABSTRACT

Objective: The purpose of this study is to examine the criteria established to determine whether a true maximal oxygen consumption (VO_2max) has been measured. Specifically, this study aims to determine whether a verification phase following a VO_2max test is necessary to confirm that a true VO_2max has been measured in a non-athlete collegiate population. **Background:** Accurate measurement of VO_2max is critical when used as a descriptive variable in exercise physiology research. Therefore, a number of criteria have been established for identification of true max measurement. However, a subject's ability to elicit these criteria consistently has been questioned (Foster et al., 2007; Midgley et al., 2006; Poole et al., 2008). As a result, affirmation of a true VO_2max has been done using a verification phase following a maximal incremental ramp test. **Methods:** This study followed a repeated measures design. Subjects performed two maximal incremental ramp tests separated by at least 48 hours. After performing the second ramp test subjects performed a 10-minute active recovery followed by a supramaximal verification test. Heart rate (HR) and expired gases were monitored continuously via a metabolic cart during all tests. RPE was taken during the final 30 seconds of each stage. Post exercise blood lactate (BL) was taken five minutes after termination of both ramp tests and the verification test. **Data Analysis:** Descriptive statistics were run for all variables. A one-way repeated measures ANOVA assessed differences between VO_2peak, RERmax, HRmax, BLmax, and RPEmax recorded during the ramp tests and verification test. Alpha level was set at 0.05. **Results:** No significant differences existed across tests for VO_2peak, HRmax, BL, and RPEmax. RERmax during the verification test was significantly different than RERmax during both ramp tests ($p < 0.01$).

Conclusion: Currently established VO_2max criteria need to be redefined. A verification phase following a maximal ramp test in a non-athlete collegiate population is not necessary to confirm true VO_2max.

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Chapter 1

INTRODUCTION

Within exercise physiology maximal oxygen consumption (VO_2max) has become one of the most common measurements performed in laboratories (Howley, Bassett, & Welch, 1995). VO_2max is defined as the product of the maximal cardiac output (L·blood·min^{-1}) and arterial venous oxygen difference (mL O_2 per L blood) (American College of Sports Medicine [ACSM], 2010). VO_2max varies significantly across populations and fitness levels, which is a result primarily of cardiac output. VO_2max, therefore, is closely related to the functional capacity of the heart. In fact it is accepted as the best index of cardio respiratory function (CRF) and has become a powerful marker of prognosis (ACSM, 2010). In experimental research VO_2max has become a commonly used descriptive variable when comparing the effects of training, exposure to altitude, pollution, and ergogenic aids.

The measurement of VO_2max dates back to the research performed by Hill and Lupton in 1923. In this study the researchers had their subjects run around an outdoor track at increasing speeds. VO_2 was measured at each speed. Hill and Lupton (1923) found that as the speed increased, so did VO_2. Eventually subjects reached a point at which VO_2 did not increase despite an increase in speed. In the nearly 90 years since this study the procedure for VO_2max testing has evolved in conjunction with the evolution of knowledge and technology. Today VO_2max is typically measured via a maximal graded exercise test (GXT) on either a treadmill or a cycle ergometer using computerized spirometers for gas analysis.

GXTs are typically held at a constant speed with incremental increases in either grade (treadmill) or resistance (cycle ergometer). Traditionally, GXTs were performed in a discontinuous fashion requiring subjects to come to the laboratory on separate days to determine VO_2max. Today, however, researchers typically employ a continuous incremental test because evidence has shown that similar VO_2max values are elicited in significantly less time when a continuous test is used (Duncan, Howley, & Johnson, 1997).

The main issue that researchers face with VO_2max testing is assuring that a true maximum has indeed been elicited. As a result a number of criteria have been developed to evaluate whether a true VO_2max has been attained. The primary criterion used to confirm that VO_2max has been elicited is a plateau in VO_2. However, a plateau in VO_2 is not seen in 100% of subjects; in fact according to Midgley, Carroll, Marchant, McNaughton, and Siegler (2009b) the incidence of a VO_2 plateau reported in previous research ranges from 0% to 100%. As a result secondary criteria have been created to use in the absence of a plateau in VO_2. Common secondary criteria used include: a respiratory exchange ratio (RER) > 1.10, a heart rate maximum ± 10-12 bpm of the age predicted maximum (220-age), a post blood lactate (BL) > 8mM, and the newest criterion the rating of perceived exertion (RPE) > 17 on Borg's 6-20 scale (Howley et al., 1995; Midgley, McNaughton, Polman, & Marchant, 2007).

Researchers have found however, that different populations and test protocols may require specific thresholds for each criterion (Misquita, Davis, Dobrovolny, Ryan, Denis, & Nicklas, 2001; Rivera-Brown & Frontera, 1998). A population that is often used in experimental research is students in college and university settings. Benson and

Swensen (2007) performed a study looking at the applicability of the criteria set by ACSM to affirm true VO_2 max with continuous treadmill and cycle ergometer GXTs which include: (1) a plateau in VO_2, (2) RER > 1.10, (3) a HR plateau, (4) post exercise BL > 8mM, and (5) an RPE > 9 or 17 depending on which Borg scale was being used. Close to 84% of the subjects tested achieved the existing criteria for RER, BL, and RPE. However, VO_2 plateau and HR criteria were found inadequate for this population.

The lack of VO_2 plateau's elicited in this population is the most troubling. Several researchers believe that without a plateau, VO_2max cannot be confirmed. Instead the highest value attained on that test is considered the peak value for that day. Recent research however, shows that a VO_2 plateau is not necessary to affirm VO_2max has been achieved. Affirmation of VO_2max has been done with the use of a verification phase following a continuous incremental GXT (Foster, Kuffel, Bradley, Battista, Wright, Porcari, Lucia, & deKoning, 2007; Midgley et al., 2009b; Poole, Wilkerson, & Jones, 2008; Rossiter, Kowalchuck, & Whipp, 2006; Snell, Stray-Gunderson, Levine, Hawkins, & Ravens, 2007).

During the verification phase subjects, after a period of rest lasting anywhere from a couple minutes to more than 24 hours, complete a constant-load test to exhaustion at either the same work load during the final stage of the incremental test, a supramaximal work load, or a submaximal work load. If the peak VO_2 values elicited are not significantly different between the two tests researchers conclude that VO_2 max has been attained (Foster et al., 2007; Midgley, McNaughton, & Carroll, 2006; Poole et al., 2008). However, the tests themselves are quite difficult on the subject and come at the cost of time for both the subject and the researchers. Research shows that VO_2peak does not differ significantly between the max and the verification tests; therefore if proper testing in laboratory settings is followed, the verification phase is unnecessary to confirm VO_2max. However, the research that exists today is limited to mostly males and athletes. A large portion of exercise physiology research is performed in college and university settings. This necessitates further research on the applicability of currently establish criteria as well as the utility of the verification phase in the non-athlete collegiate population.

Statement of the Purpose

The purpose of this study is to examine the criteria established to determine whether a true VO_2max has been attained. Specifically, this study aims to determine whether a verification phase following a maximal incremental ramp test is necessary to confirm that a true VO_2max has been measured in a non-athlete collegiate population.

Hypotheses

The null hypotheses for this study are:

1. There will not be a significant difference between the VO_2peak elicited during the incremental ramp tests and during the constant load verification test.
2. There will not be a significant difference between the RERmax, HRmax, post exercise BL, and RPE values achieved following the incremental ramp tests and the constant load verification test.

Assumptions of the Study

For the purpose of this study, the following assumptions will be made at the start of the investigation:

1. The subjects are representative of the typical college and university undergraduate population.
2. The subjects will provide honest answers to the questions on the health history questionnaire.
3. The subjects will follow the instructions outlined for them in the pretest instructions.
4. Each subject will give a maximal effort on both the continuous incremental graded exercise test and the verification test to volitional exhaustion.

Definition of Terms

The following terms are operationally defined for the purpose of this investigation:

1. Maximal Oxygen Consumption (VO_2max): The product of the maximal cardiac output (L blood·min^{-1}) and arterial-venous oxygen difference (mL O_2 per L blood) (ACSM, 2010).
2. Peak Oxygen Consumption (VO_2peak): The highest value of VO_2 measured during a graded exercise test (McArdle, 2010).
3. Graded Exercise Test (GXT): An exercise test with either incremental steps or a constant load in which the goal is to elicit a VO_2max.
4. VO_2 Plateau: A change in VO_2 less than 2.1 ml·kg^{-1}·min^{-1} or 150 mL·min^{-1} from one workload to the next.
5. Respiratory Exchange Ratio (RER): A measure of the amount of carbon dioxide produced against the amount of oxygen consumed.
6. Age Predicted Maximal Heart Rate (APHRM): A prediction of the maximal heart by subtracting the subject's age from 220.

7. Post Exercise Blood Lactate Concentration (BL): A measure of the amount of lactic acid that has accumulated in the blood during exercise.
8. Rating of Perceived Exertion (RPE): A Borg scale from 6 to 20 used by subjects to report their overall sensation of effort.

Delimitations

The delimitations of this investigation include:

1. The study only used non-athlete undergraduate students from Ithaca College.
2. VO_2, as well as the previously mentioned criterion used to determine true VO_2max (RERmax, HRmax, BL, and RPE) were the only variables measured.
3. A TrueMax 2400 metabolic cart (Parvomedics; Sandy, UT), a heart rate monitor (Polar; Lace Success, NY), a lactate analyzer (Lactate Scout; Senslab; Leipzig, Germany), and an RPE scale were used to measure the above.

Limitations

The limitations of this investigation include:

1. The results of the study are generalized to a non-athlete undergraduate population from one small northeastern college.
2. The results only indicate whether a verification phase is necessary for confirmation of true maximal testing on a cycle ergometer from a non-athlete undergraduate population from one small northeastern college.
3. Results are only applicable to the metabolic cart, heart rate monitor, and lactate analyzer used.

Chapter 2

REVIEW OF LITERATURE

Introduction

According to ACSM's Guidelines for Exercise Testing and Prescription the accepted criterion for the measurement of cardiorespiratory fitness (CRF) is maximal oxygen consumption (VO_2max), (ACSM, 2010). Accurate measurement of CRF allows exercise professionals to prescribe appropriate exercise (i.e., intensity, duration and mode) on an individual basis. Due to its ability to supply valuable information in regards to CRF, VO_2max testing has become one of the most common procedures performed in the exercise physiology laboratory (Midgley & Carroll, 2009a). This literature review will focus on VO_2max testing procedures. Specifically, it will discuss the methods used to determine whether a true VO_2max has been achieved. Special focus will be placed on the criteria that have been established to determine whether a subject has elicited a true max.

Graded Exercise Testing

VO_2max is typically measured with a graded exercise test (GXT). In an iconic study performed by Taylor, Buskirk, and Henschel (1955), to describe the technique used to determine VO_2max, its limitation, and its usefulness as a measurement technique, male soldiers and university students were recruited to perform a VO_2max test. Taylor and colleagues (1955) used a discontinuous test, which required the subjects to come into the laboratory on three or more separate days (usually a week apart) to perform each stage of the exercise test. The test was performed on a treadmill with the speed held constant but in each subsequent stage the grade of the treadmill was increased 2.5%. Discontinuous incremental testing continued to be the norm for VO_2max testing until it was shown that continuous incremental testing could produce the same VO_2max but in significantly less time.

McArdle, Katch, and Pechar (1973) had 15 male undergraduates perform six separate GXT protocols. The tests included a continuous bike test, a discontinuous bike test, the Balke treadmill test, the Mitchell, Sproule and Chapman treadmill test, a continuous treadmill test, and a discontinuous treadmill test. Continuous testing requires the subject to visit the laboratory once performing each stage one right after the other to volitional exhaustion. When comparing the discontinuous tests to the continuous tests the VO_2max elicited were not significantly different. The time however, was significantly less for both the continuous bike and treadmill test when compared to the other four protocols. Due to the similarities in the VO_2max values the researchers concluded that the continuous test would be preferred especially in experimental settings where a large number of tests will be performed.

VO_2 max Criteria

Regardless of the testing protocol being used the main issue facing researchers is the ability to establish that VO_2max has indeed been elicited. As a result a number of criteria were established to determine that a "true" VO_2max has been elicited. The primary criterion used to confirm that VO_2max has been elicited is a plateau in VO_2 as established by Taylor and colleagues (1955). Other secondary criterion established by ACSM include: (1) a respiratory exchange ratio (RER) > 1.10, (2) failure of heart rate (HR) to increase with further increase in exercise intensity, (3) a post blood lactate (BL) > 8mM, and (4) a rating of perceived exertion (RPE) > 17 on Borg's 6-20 scale.

VO2 Plateau

Since the study by Taylor and colleagues (1955) a plateau in VO_2 has been accepted as the primary criterion for determination of VO_2max. In the study Taylor and colleagues (1955) defined a plateau as seeing a rise in VO_2 less than 150 $mL \cdot min^{-1}$ from one workload to the next. This threshold was chosen because it represented half of the mean increase in VO_2 (299.3 $mL \cdot min^{-1}$, SD = 86.5) in response to an increase in treadmill grade of 2.5%. In the almost 60 years since it's publication this threshold value has been applied to various maximal exercise tests irrespective of the protocol employed and the population being tested.

However, the problem many researchers face is that a varying percentage of subjects in fact elicit a VO_2 plateau. As a result researchers have begun speculating as to whether a plateau in VO_2 is necessary for determination of a "true" max. In a study performed by Day, Rossiter, Coats, Shasick, and Whipp (2003), 71 males, ranging in age from 19-61 performed a maximal continuous incremental GXT on a cycle ergometer. Only 12 of the 71 participants at termination exhibited a plateau in VO_2. In a subsequent study performed by the same group, Rossiter and colleagues (2006) had seven healthy males ranging in age from 20-48 perform a maximal continuous test on a cycle ergometer. Not a single subject elicited a plateau during the incremental portion of testing. Again this group of researchers demonstrated that a plateau in VO_2 was not necessary in order to determine a true VO_2max.

As VO_2max testing has become relevant for cardiorespiratory capacity and diagnostic purposes in alterative populations (children, sedentary, elderly etc.), again researchers have found a varying amount of subjects eliciting a plateau in VO_2. Rivera-

Brown and Frontera (1998) found that in maximal incremental testing of trained adolescents on various ergometers there was a large variation of subjects who elicited a plateau in VO_2 (as defined by Taylor et al., 1955) depending on the ergometer used. As a result, the researchers concluded that a plateau in VO_2 should not be a requirement for determination of VO_2max among adolescents. Misquita and colleagues (2001) came to the same conclusion when only 15% of the obese, postmenopausal women studied elicited a plateau in VO_2. Due to the varying number of subjects across populations in the literature that elicit a plateau, secondary criterion (RER, BL, HR, and RPE) have been developed to determine if a true max has been achieved in the absence of a plateau.

Respiratory Exchange Ratio

When a discernable VO_2plateau is not observed, respiratory exchange ratio (RER) has been the most common criterion used to confirm VO_2max has in fact been achieved (Poole et al., 2008). RER is a measure of the amount of carbon dioxide produced against the amount of oxygen consumed. One of the reasons RER is considered a good indicator of VO_2max is due to the reaction between rising hydrogen ion concentration (H^+) and plasma bicarbonate (HCO_3^-) during metabolism:

$$H^+ + HCO_3^- \text{ è } H_2CO_3 \text{ è } H_2O + CO_2$$

As the concentration of carbon dioxide (CO_2) increases ventilation increases, and in turn the RER increases. As a person moves towards max CO_2 production will typically outweigh oxygen consumption. ACSM (2010) has stated that when an individual elicits an RER > 1.10 during a graded exercise test a maximal effort can be said to have occurred. However, ACSM (2010) notes that there is considerable interindividual variability in this response. The considerable variability in threshold levels is in the literature as well. Threshold for confirmation of VO_2max ranges from ≥ 1.00 to 1.15 depending on the population being tested.

In an effort to determine the best threshold value, Midgley and colleagues (2009b) evaluated common RER threshold levels between male runners and cyclists that performed maximal exercise tests. The common RER threshold levels studied included: ≥ 1.05, ≥ 1.10 and ≥ 1.15. When threshold was set at ≥ 1.05 all subjects met the criterion. When RER threshold was set at ≥ 1.10 all subjects except one runner met the criterion. However, when RER threshold was set at ≥ 1.15 only four out of ten runners met the criterion whereas all cyclists met the criterion (Midgley et al., 2009b). One explanation that Midgley and colleagues (2009b) proposed for the differences at the higher threshold level is that cycling requires greater muscular force output than running, which may result in greater recruitment of fast twitch muscle fibers. Fast twitch muscle fibers have a greater capacity for glycolytic metabolism and in turn produce more lactate resulting in an increased need for lactate clearance, shifting the equation above to the right. The apparent differences seen in this study between running and cycling responses to maximal testing caused the authors to conclude that there is a need for protocol dependent criteria.

Further evidence for the necessity of protocol dependent criteria was provided by Poole and colleagues (2008). Eight healthy but not highly trained subjects performed a maximal ramp cycle ergometer test. The researchers set threshold RER at > 1.10 and found that all but one subject met the criteria. In fact, average RER at max was 1.24 ± 0.03. Average VO_2 at the criterion level of RER > 1.10 was 2.97 ± 0.24 $L \cdot min^{-1}$ and 3.41 ± 0.15 $L \cdot min^{-1}$ at an RER > 1.15, both of which were significantly lower than the average

VO_2max (Poole et al., 2008). In this instance the use of the established RER criteria would have resulted in significant underestimation of VO_2max. Despite the apparent differences in RER elicited on different ergometers the same threshold of > 1.10 continues to be used to confirm true max.

Unfortunately, differences also exist depending on the population being tested for RER. Rivera-Brown and Frontera (1998) addressed this issue by examining RER responses to maximal exercise testing among trained adolescents. The RER threshold level was set at > 1.00. The adolescents performed maximal tests on a treadmill, cycle ergometer, as well as a rowing machine. All subjects met the RER criterion for VO_2max on all ergometers, indicating that a proper threshold level was used. Regrettably, this is not always the case as seen in the study performed by Misquita and colleagues (2001) where obese, postmenopausal women performed maximal treadmill tests. Threshold RER was set at the standard level of > 1.10. Of the 108 women tested only 57% achieved an RER > 1.10. Misquita and colleagues (2001), like Poole and colleagues (2008), call for redefinition of the RER criteria.

The goal of threshold criteria in general is to establish ones that can be used across the board no matter the protocol or population. Unfortunately, it appears RER is not a criterion that can be established across the board as is evidenced in the current literature. However, if a threshold is properly set for protocol and population, RER is one of criteria that consistently met during maximal exercise testing.

Maximal Heart Rate (HRmax)

HRmax is also a very common secondary criterion used to determine VO_2max. HRmax can be predicted by age through the use of a number of published equations. The most common equation is 220-age (ACSM, 2010). Tanaka, Monahan, and Seals (2001) however, developed a second equation for age predicted maximal heart rate (APMHR) of 208 – (0.7 · age), based on a meta-analytic approach that used group mean HRmax values from 351 different studies. However, equations that rely on age as a predictor of maximal heart rate are subject to a high intersubject variability with a standard deviation of ±10-12 beats per minute (bpm) (ACSM, 2010). Midgley and colleagues (2007) believe the intersubject variability may be even greater and cites that the 95% confidence interval has been reported as high as 45 bpm.

Within the literature today there is also great variability in the HR criteria used with some researchers using a range as great as ± 15 bpm around APMHR to attainment of a set percentage of APMHR ranging from 85 to 100% (Midgley et al., 2007). In the study performed by Poole and colleagues (2008) the HR criteria for determination of a "true" max effort was set at achievement of ± 10 bpm (or 5%) of APMHR. Of the eight subjects tested, five achieved HRmax ± 10 bpm. Two of the three subjects who did not achieve ± 10 bpm of APMHR, however, did show a plateau in VO_2 as well as an RER > 1.15 at max. This is further indication that HR is not a reliable indication of a maximal effort.

The unreliability of HR as a criterion is also evidenced in the research performed by Duncan and colleagues (1997) where continuous and discontinuous protocols were compared. HR criteria was set at ≥ APMHR. Their findings indicated that during the discontinuous protocol only, 10% of subjects met the set criteria while 40% met the criteria during the continuous protocol. When the HR criteria was expanded to within ± 10 bpm, 70% of subjects met the criteria during the discontinuous protocol, whereas 60%

met the criteria during the continuous protocol. The interesting finding from this study is that the original criteria were defined using a discontinuous protocol; however fewer subjects met the criteria initially within the discontinuous protocol. Despite the disparity seen within the literature today, HR is still used frequently as a criterion for determination of VO_2max.

ACSM (2010) has recognized the large variability when utilizing HR as a criterion, making a point to state that achievement of APMHR should not be used as an absolute endpoint for a graded exercise test. In terms of true max criteria ACSM has defined the heart rate criteria as follows, "failure of heart rate to increase with further increases in exercise intensity" (ACSM, 2010, p. 143). In other words, individuals should exhibit a plateau in heart rate ($HR_{plateau}$) similar to the VO_2 plateau at max. To evaluate whether a $HR_{plateau}$ in fact occurs, Benson and Swensen (2007) had 65 undergraduate students perform maximal continuous GXTs on both a treadmill and a cycle ergometer. The researchers calculated and defined $HR_{plateau}$ for both protocols as a percentage of mean change in HR per stage. A plateau in HR according to their definition occurred in 40% of the trials. Therefore, the researchers state further testing is needed to validate the "new" HR criteria (Benson & Swensen, 2007).

<u>Post Exercise Blood Lactate (BL)</u>

A third secondary criterion for the determination of VO_2max that is commonly used is post exercise blood lactate concentration (BL). According to Howley and colleagues (1995), blood lactate is a good choice as an indicator of maximal effort because higher levels are associated with the recruitment of fast-twitch muscle fibers, the rapid elevation of plasma epinephrine concentration, and a reduction in liver blood flow that occurs during heavy exercise. However, similar to the VO_2 plateau, the threshold value for BL has been inconsistent over the years. ACSM (2010) has established that this criterion has been met if an individual attains a BL > 8mM. This criterion was established based on the research performed by Astrand (1952) in which boys and girls aged 14-18 were used as subjects performing a discontinuous maximal exercise test. Despite the limited population studied that determined this threshold criterion it is still widely used across all age groups.

In an effort to determine whether the BL criterion of > 8 mM applied across protocols, Duncan and colleagues (1997) recruited 10 healthy males and compared their physiological responses to both a discontinuous and a continuous treadmill protocol. The BLs averaged 14.3 mM ± 2.7 and 11.9 ± 2.7 respectively (Duncan et al., 1997). These high values may indicate that the subjects reached the established threshold value at submaximal workloads (Howley et al., 1995). This indicates that the threshold level established in the early 1950s may in fact be set too low. However, other research has not come to the same conclusion (Midgley et al., 2009b; Rossiter et al., 2006). In fact the BL criterion threshold level may be modality dependent as well as population dependent.

In order to compare the physiological responses across modalities, Midgley and colleagues (2009b) had 20 male athletes (10 runners and 10 cyclists) perform maximal tests on their respective modalities. Due to technical problems data was only collected on six of the runners treadmill tests and nine of the cyclists cycle ergometer tests. Only four of the runners achieved a post exercise BL ≥ 8mM, whereas all nine of the cyclists achieved a post exercise BL ≥ 8mM. When the post exercise BL threshold was increased to ≥ 10mM only one of the runners achieved this threshold whereas eight of the nine cyclists tested achieved this threshold. The researchers therefore concluded that post exercise BL response is largely dependent on the population, exercise modality, as well as the test protocol, or a combination of these factors.

Further indication of the number of factors that come into play in regards to post exercise BL was provided by Poole and colleagues (2008). Eight healthy males performed a ramp style maximal cycle ergometer test. The average post exercise blood lactate concentration was 7.1 ± 0.3mM (Poole et al., 2008). Considering the results discussed above the researchers expected post exercise BL values well above 8mM. Instead the authors disagreed with Howley and colleagues (1995) who had stated that blood lactate was a good indicator of maximal effort. In fact, Poole and colleagues (2008) called for a more viable strategy for confirming a maximal effort had been performed.

Rating of Perceived Exertion

Of the secondary criteria, the newest is the subjective measure of the rating of perceived exertion (RPE). The most common RPE scale used is Borg's 15-point RPE scale, which is ranked from 6-20 to mirror heart rate values from rest to maximum. Subjects are asked to choose a ranking based on their total body exertion rather than a single aspect such as leg fatigue or dyspnea during each stage of a GXT. Midgley and colleagues (2007) in order to create a better picture of the criteria used in relevant literature collected articles from prominent journals and summarized the various criteria employed into a table. Among the 275 articles assessed, the threshold value for RPE ranged from >17 to ≥ 19. ACSM has established a threshold value of >17 as a test that has induced a maximal effort.

Despite the regular use of RPE during maximal GXTs, a lack of literature involving the assessment of VO_2max report RPE as a criteria for determination of a "true" max. In the same article mentioned above, Midgley and colleagues (2007) found only 9 of the 275 articles cited included RPE as a criterion. In an effort to add to the literature base for the utility of RPE as a criterion Benson and Swensen (2007) included it in a study in which, 65 undergraduates were recruited to complete a continuous GXT on both a treadmill and cycle ergometer. The researchers reported an average RPE at max as 17.7 with 83% of RPEs recorded at $\geq$ 18, indicating that in the undergraduate population ACSM's standard criterion of > 17 a valid measure of maximal effort.

Unfortunately, the RPE criterion, a subjective measure, has been scrutinized because of its one-dimensional approach to the measurement of perceived exertion (Midgley et al., 2007). Alternatively, Midgley and colleagues (2007) suggest that a multidimensional measure may better evaluate the complex psychophysiological nature of effort. However, if investigators give proper instructions, RPE could be one of the best criterions available as indicated by Benson and Swensen (2007) who demonstrated that the average RPE at max was above ACSM's (2010) standardized criterion of > 17.

Verification Phase

In spite of the scrutiny that has been placed on the above-mentioned criteria, no "new" criteria have been established. A plateau in VO_2 is still the primary criterion used. In its absence one proposed alternative to the use of criteria to establish a "true max" is the use of a verification phase. The earliest mention of the verification phase was by Thoden in the early 1980s. Thoden, MacDougall, and Wilson (1982) suggested that after 15 minutes of recovery following an incremental test that each subject perform a constant load test at a one additional workload than that performed during the final stage of the incremental test to the limit of tolerance. The presumption being that if the VO_2peak elicited during the verification phase is consistent with the one elicited during the GXT then the researchers would establish a greater confidence that "true max" had been attained. Midgley and colleagues (2006) sought to prove that the verification phase was a valid measure of true max. In doing so Midgley and colleagues (2006) made the point that conceptually the verification phase is similar to the plateau criterion established by Taylor and colleagues (1955) when applied to discontinuous protocols. Simply meaning that the verification phase serves as a way to produce a plateau from the final stage of the incremental test to the verification test. Since the 1980s, the theory behind the verification phase has remained the same but the protocol has varied, namely the timing of when the verification phase should take place.

The verification phase, depending on the researchers, has taken place in as few as 1-3 minutes following a GXT to as long as a few days following. For example, in a study performed by Poole and colleagues (2008) eight healthy, recreationally active males performed an incremental ramp test on a cycle ergometer. On a separate day the participants returned for a constant load verification test at a work-rate 105% of the maximal work-rate achieved on the incremental ramp test. Poole and colleagues (2008) did not see a significant difference between the VO_2peak achieved during the incremental ramp test (mean ± SE, 4.03 ± 0.1 $L \cdot min^{-1}$) and the VO_2peak achieved during the verification phase (3.95 ± 0.1 $L \cdot min^{-1}$). Therefore, Poole and colleagues (2008) concluded that the verification test confirmed that the highest VO_2 achieved during the incremental ramp test was VO_2max.

Snell and colleagues (2007) performed a similar test with 52 male and female collegiate middle-distance runners. After completing an incremental test on a treadmill the participants returned the following day to complete a verification test to exhaustion at a supramaximal level (~30% greater than the work rate achieved during the final stage of the incremental test performed a day earlier). The researchers reported that there was no significant difference between the VO_2peak achieved during the incremental test (mean ± SD, 63.3 ± 6.3 $mL \cdot kg^{-1} \cdot min^{-1}$) and the supramaximal verification test (62.9 ± 6.3 $mL \cdot kg^{-1} \cdot min^{-1}$) (Snell et al., 2007). In fact, the researchers noted that most individuals elicited almost identical VO_2peak values on the different tests. The others elicited a VO_2peak on the supramaximal verification test lower than that which they achieved on the incremental test (Snell et al., 2007).

Midgley and colleagues (2009b) also saw a non-significant difference in VO_2peak values between an incremental test and a verification phase when he tested 20 male athletes (10 runners and 10 cyclists) despite the fact that the verification phase was performed following only 10 minutes of passive rest after completing the incremental ramp test. The participants performed a verification test at one work rate greater than the work rate max achieved during the incremental ramp test to limit of tolerance. Eighteen of the subjects fulfilled the VO_2 verification criterion with a non-significant difference between VO_2peak elicited during the incremental test and the VO_2peak during the verification phase (95% CI, -86,129; $t = 0.4$; $p = 0.7$) (Midgley et al., 2009b). The non-significant difference led the authors to conclude a VO_2max had been elicited.

Rossiter and colleagues (2006) further limited the time between the incremental ramp (IR) test and the verification phase (VT) cutting the time that Midgley and colleagues (2009b) used in half, when testing seven healthy males. The researchers limited the rest time between tests to five minutes. The work rate for the verification phase was set at a supramaximal level of ~5% greater than the peak work rate achieved during the incremental ramp test. The peak VO_2 values were not significantly different between the two tests (RI $\bar{x} = 4.33$ L·min^{-1} (SD 0.51); VT $\bar{x} = 4.30$ L·min^{-1} (SD 0.52) $p = 0.49$) (Rossiter et al., 2006). The researchers also reported the VO_2peak values of the two tests were highly correlated ($r = 0.98$). In addition, Rossiter and colleagues (2006) also had five of the subjects return five days after the initial testing to perform an additional incremental ramp test and a verification test at a work rate ~5% less than the peak work rate achieved during the incremental ramp test that day. The peak VO_2 values again were not significantly different between the two tests (RI $\bar{x} = 4.11$L·min^{-1} (SD 0.48); VT $\bar{x} = 4.12$ L·min^{-1} (SD 0.53) $p = 0.78$) (Rossiter et al., 2006). Again the researchers noted that the values on the second day were highly correlated as well ($r = 0.99$) (Rossiter et al., 2006). The peak VO_2 values for the five subjects who performed all four tests were not significantly different despite the differences in work rates used. The researchers concluded that it was unlikely that the two different tests could result in almost identical but submaximal VO_2 values in both instances. Therefore, VO_2max could be confirmed assuming maximal effort was given on both tests.

Foster and colleagues (2007) attempted to further limit the time required to confirm that a "true" max had been attained by having subjects complete the verification test either one minute (cycle ergometer test) or three minutes (treadmill test) following completion of an incremental ramp test. In both instances, despite differences in the active rest period, there was not a significant difference between the VO_2peak elicited during the incremental ramp and verification tests. Foster and colleagues (2007) concluded therefore, that VO_2peak is unlikely to change between successive maximal bouts of exercise.

The verification phase, despite its limited use within the recent literature, has been shown to reproduce VO_2peak. With a lack of standardized criterion that is valid across protocols and populations, it may in fact be the best tool for verifying that a true maximum has been achieved. However, if testing is performed in controlled settings such as in college or a university laboratory, the question becomes is the verification phase necessary?

Numerous researchers have reproduced VO_2peak values. Day and colleagues (2003) had 71 males and perform an incremental ramp test on a cycle ergometer to maximal exertion. Of the original 71, 38 returned to perform a constant load test to limit of tolerance test at an average of ~90% of the peak work rate attained during the incremental test. In addition six of the 38 competed an additional five constant load tests, in a randomized order at different work rates. The mean VO_2peaks from the constant load tests (4.51 ± 0.4 $L \cdot min^{-1}$) and the incremental tests (4.50 ± 0.3 $L \cdot min^{-1}$) did not differ significantly in the six subjects ($p < 0.01$) (Day et al., 2003). To save time and materials, the question remains: do we need the verification test? The researchers even in the absence of the constant load tests would have come to the same conclusion for VO_2max in this instance even if the verification test were not performed. Therefore, as long as proper procedures are followed, it appears that VO_2peak may be accepted as VO_2max even without the utility of a verification phase.

Summary

VO_2max testing has been established as an important staple in exercise physiology laboratories. Since its inception in the early 1920s, testing procedures have changed and evolved. Despite these changes, the necessity for developing criteria that accurately confirm that a VO_2max has been elicited has not changed. Accurate criteria are important seeing as VO_2 is a common variable used in exercise physiology to evaluate the effectiveness of for example, specific training programs or an ergogenic aid.

ACSM (2010) has established a number of criteria for determination of VO_2max including a plateau in VO_2, an RER > 1.10, attaining APHRM, post exercise BL > 8mM, and RPE > 17. Many of these criteria were established using a single modality, population, and/or protocol, but their applicability to alternative forms of testing have not been evaluated. As evidenced by the literature reviewed here many of these criteria have come into question. The VO_2 plateau criterion in particular has a large amount of scrutiny placed on it due to the fact that it is largely considered a prerequisite for determination of VO_2max. The scrutiny is owed considering studies have reported anywhere from 0 to 100% of its subjects achieving a plateau (Midgley & Carrol, 2009a). The secondary criteria proposed do not come without scrutiny as was evidenced in the literature reviewed here. The verification phase is promising but few studies use it.

The aim of this study is to expand upon the current research in regards to VO_2max testing and the criterion for establishment of a "true" max. Specifically, this study seeks to determine if a verification phase is necessary in the non-athlete college population when performing maximal continuous incremental tests on a cycle ergometer. This population is a commonly studied one within college and university settings. Previously, a large focus has been placed on studying the utility of the verification phase among athletes (Foster et al., 2007; Midgley et al., 2009b; Snell et al., 2007). Not only is the focus largely on athletes, but males as well (Day et al., 2003; Midgley et al., 2009b; Poole et al., 2008). Foster and colleagues (2007) as well as Snell and colleagues (2007) tested both males and females but in both instances the females were either athletes and/or not in the college population. There is very little research on the applicability of the verification phase to both the male and female non-athlete collegiate population, therefore this study aims to fill this void within the research.

Chapter 3

METHODS

Subjects

Seventeen (8 male and 9 female) non-athlete undergraduate students (N = 17) from Ithaca College's School of Health Sciences and Human Performance's Anatomy and Physiology class were recruited to participate in this study. Non-athlete subjects were selected in order to present a typical college population that participates in common university setting studies. Subjects were offered extra credit for participation.

Experimental Procedures

The investigation began after obtaining approval from Ithaca College's Human Subjects Review Board. Subjects were informed of the study protocol, including both the risks and benefits of participation. All subjects were given an opportunity to ask questions. Then each subject was required to thoroughly read and sign an Informed Consent (Appendix A) form as well as complete a medical history questionnaire (Appendix B). Prior to coming to the laboratory on both days each subject was given pretest instructions (Appendix C). On the day of testing each subject was asked to complete a 24-hour history form (Appendix D) to determine that pretest instructions were followed. If pretest instructions were not followed testing was rescheduled for another day.

Testing took place on two days separated by approximately 48 hours in Ithaca College's Center for Health Sciences Exercise Physiology Laboratory. On the first day of testing each subject completed a maximal incremental ramp test on a cycle ergometer. The test was terminated when the subject reached volitional exhaustion or when the subject could no longer maintain the workload (Benson & Swensen, 2007). On the second day of testing, subjects performed a second maximal incremental ramp test on a cycle ergometer. After 10 minutes of active rest each subject completed a constant-load verification test at the workload greater than the final workload achieved during the maximal incremental ramp test. Both tests were terminated when the subject reached volitional exhaustion. In an attempt to assure that a maximal effort was given each subject was also verbally encouraged throughout the tests by the three researchers present.

Upon arrival to the laboratory each subject had height and weight measured. Subjects were first instructed by the researcher to be barefoot. To measure height the researcher instructed each subject to stand against the height chart attached to the wall. Then the subject was instructed to take a deep breath as the researcher drew the sliding caliper to rest on the subject's head. The height of the subject was recorded. To measure weight the researcher instructed each subject to step on the scale after insuring that the scale read zero beforehand. Once the subject stepped on the scale the dials were moved from left to right until the scale bar appeared to be balanced. The researcher then recorded the subject's weight. Each subject was then fitted with a heart rate monitor chest strap (Polar; Lake Success, NY).

The subjects were then taken over to the cycle ergometer. The researcher adjusted the seat height of the cycle ergometer to the subject's anterior superior iliac crest in order to obtain almost full leg extension. The subject then warmed up at 0.5 kp for five minutes. Following the warm up each subject was fitted with a nose clip as well as a headgear that included a mouthpiece attached to a hose connected to a TrueMax 2400 metabolic cart (Parvomedics; Sandy, UT) that continually monitored expired ventilatory gases. The metabolic cart was calibrated prior to each test.

The maximal incremental ramp test was performed at a rate of 80 rpm or greater. The first two-minute stage started at a workload of 1.0 kp and 1.5 kp respectively for females and males. The resistance increased 0.5 kp every two minutes until the subject could no longer maintain 80 rpm or had reached volitional exhaustion. HR and RPE were manually recorded during the final 30 seconds of each workload. The metabolic cart continuously measured VO_2 and RER throughout the test. Upon termination of the test the headgear and nose clip were removed and the subject performed a five-minute cool down. Approximately five minutes after termination, one of the subject's fingertips was swabbed with alcohol and then swabbed again with clean gauze before a sterile lancet was used to acquire a blood sample for lactate analysis. Each subject was then dismissed for the day.

Approximately 48 hours later each subject returned to the laboratory and completed a second maximal incremental ramp test. The test followed the exact same procedures used during the first test performed on day one. The test terminated when volitional exhaustion was achieved or 80 rpms could no longer be maintained. At termination the nose clip and headgear attached to the metabolic cart were removed and each subject performed a 10-minute active recovery at 0.5 kp.

Approximately five minutes into the active recovery, another sample of blood was taken for BL analysis using the same method described previously. Once BL was taken, each subject completed the rest of the active recovery. During active recovery the metabolic cart was once again calibrated.

At the end of the active recovery each subject was fitted with the nose clip and the headgear attached to the metabolic cart. After being fitted with the headgear and nose clip the researcher placed the resistance on the flywheel so that it was set at one workload above the final workload achieved during the maximal incremental ramp test. The subject continued at that workload until volitional exhaustion was achieved or until 80 rpms could no longer be maintained. Upon termination of the test the nose clip and headgear were immediately removed and the subject was allowed to cool down for five minutes. Approximately five minutes after termination of the constant-load test a final blood sample was taken for BL analysis. Each subject was then briefed about the results of the three tests and dismissed.

Instruments

Rating of Perceived Exertion

Rating of perceived exertion was assessed using Borg's 15-point scale (Borg, 1974). The scale is ranked from 6-20 to mirror heart rate values from rest to maximum since Borg (1974) discovered ratings of perceived exertion and heart rate had a 0.85 Pearson correlation. Subjects during the final 30 seconds of each stage rate on the numerical scale their perceived feelings relative to their exertion level. ACSM (2010) stated that an RPE > 17 indicates that a maximal effort has been given in regards to maximal exercise testing.

Medical Health History

Participants completed a medical health history form (Appendix B) before participation to determine if any medical conditions existed that were contraindications to exercise testing. If a contraindication was identified the individual was not allowed to participate.

Pretest Instructions

All participants were provided with pretest instructions (Appendix C) approximately 48 hours prior to the first day of testing. The instructions needed to be followed in order to accurately measure VO_2max as well as to prevent participants from getting sick during or after testing.

24-Hour Health History

Prior to testing on both days, a 24-hour history form (Appendix D) was completed by participants to verify that pretest instructions had been followed. The form was also used to make sure that participants were in a similar physical condition from test day one to test day two. If pretest instructions were not followed or physical condition changed significantly (e.g., a cold presented) testing was rescheduled.

Data Collection Sheet

Researchers recorded height, weight, blood lactate, RPE, time of test, and any comments regarding the tests on the data sheet (Appendix E). Measurements recorded by the metabolic cart (VO_2, RER, HR) were also manually recorded during the final 30 seconds of each stage to serve as a backup if the computer inaccurately recorded the measurements.

Monark Bicycle

The Monark Bicycle (Monark; Stockholm, Sweden) was the bike used by all participants during all exercise tests.

ParvoMedic Metabolic Cart

The ParvoMedic metabolic cart (Sandy, UT) was used to collect and measure all expired gases continuously during the exercise test.

Polar Heart Rate Monitor

Participants wore a Polar heart rate monitor (Lake Success, NY) during the exercise tests. The monitor allowed researchers to continuously monitor heart rate.

Scout Blood Lactate Analyzer

The Scout blood lactate analyzer (Senslab; Leipzig, Germany) was used to measure post exercise blood lactate following the two maximal incremental ramp tests and the verification test.

Tanita Wall Height Chart

The wall height chart (Tankita; Arlington Heights, IL) was used to measure participant's height when participants first visited the laboratory.

Detecto Weight Scale

The weight scale (Detecto; Webb City, MO) was used to measure participants weight prior to testing on both days the participants visited the laboratory.

Data Analysis

Descriptive statistics were run for all variables measured. One-way repeated measures ANOVA were run to determine whether a significant difference existed among measures of VO_2max, RERmax, HRmax, BLmax, and RPEmax values recorded from the maximal incremental ramp tests and the verification test. All statistics were performed using SPSS 19.0, with the alpha level for all analyses set at .05.

Chapter 4

RESULTS

The purpose of this study was to examine ACSM's currently established criteria for determination of VO_2max as well as determine whether a verification test was necessary to confirm VO_2max. The following chapter describes the data collected from the study described above. Descriptive analyses are presented first followed by repeated measures ANOVAs .

Descriptive Statistics

Descriptive statistics of subjects' anthropometric data as well as exercise habits are presented in Table 1.

Table 1

Descriptive statistics of study participants

	Minimum	Maximum	Mean	Standard Deviation
Age (y)	18	22.0	19.1	1.2
Height (cm)	150	188.0	168.3	9.6
Weight (kg)	50	93.2	68.8	11.8
Average Exercise/Week (days)	0	6.0	3.4	1.8

VO_2max Criteria

The threshold criterion and the number of subjects that fulfilled each criterion for the separate tests are presented in Table 2.

Table 2

Number of subjects who satisfied threshold criteria for determining VO_2max

	Test 1	Test 2	Verification
VO_2 Plateau (< 150 $mL \cdot min^{-1}$)	10	7	n/a
RER (> 1.1)	13	14	8
HR (± 10 bpm)	7	7	5*
BL (> 8mM)	13	13	13
RPE (> 17)	16	15	14

Note. RER = Respiratory exchange ratio; HR = Heart rate; BL = Post exercise blood lactate; RPE = Rating of perceived exertion; * Due to technical problems, data was only available for 15/16 of the tests.

VO_2 Plateau

Of the 16 subjects tested 11 (68.75%) elicited a plateau in VO_2 during at least one of the continuous incremental tests. Of the 11, six (37.5%) elicited a plateau in VO_2 during both of the maximal incremental ramp tests. The remaining five participants (31.25%) did not elicit a plateau in either maximal incremental ramp tests. However, four of the five participants elicited a plateau between the final stage of the second maximal incremental ramp test and the verification phase.

Maximal Respiratory Exchange Ratio

Descriptive statistics for RERmax values recorded during the maximal incremental ramp tests as well as the constant load verification test are presented in Table 3. A one-way repeated measures ANOVA was performed to determine if there was a significant difference across the three tests. Mauchly's test indicated that the assumption of sphericity had been violated $\chi^2(2) = 10.86$, $p < 0.01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.65$). The results show that RER was significantly affected by the test being performed, $F(1.3, 19.48) = 10.15$, $p < 0.01$. Post hoc pair-wise comparison analyses revealed that RERmax recorded during Test 1 was significantly different than RERmax recorded during the verification test ($p = 0.01$). RERmax recorded during Test 2 was significantly different than RERmax recorded during the verification test ($p = 0.01$).

Table 3

Descriptive statistics of RERmax values recorded during three maximal tests

	Minimum	Maximum	Mean	Standard Deviation
RERmax Test 1	1.05	1.32	1.19	0.07
RERmax Test 2	1.01	1.32	1.18	0.08
RERmax Verif	0.79	1.26	1.08	0.12

Note. RERmax = Maximal respiratory exchange ratio; Verif = Verification phase.

Maximal Heart Rate

Descriptive statistics for HRmax (bpm) values recorded during the maximal incremental ramp tests and the time to exhaustion verification test are presented in Table 4. A one-way repeated measures ANOVA was performed to determine if there was a significant difference across the three tests. Mauchly's test indicated that the assumption of sphericity had been violated $\chi^2(2) = 12.81, p < 0.01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.62$). The results show that HRmax was not significantly affected by the test being performed, $F(1.23, 17.21) = 3.95, p > 0.05$.

Table 4

Descriptive statistics of HRmax values recorded during three maximal tests

	Minimum	Maximum	Mean	Standard Deviation
HRmax Test 1 (bpm)	179	205	189.6	8.3
HRmax Test 2 (bpm)	176	205	188.9	9.9
HRmax Verif (bpm)	149	199	184.5	13.2

Note. HRmax= Maximal heart rate; Verif = Verification phase.

Post Exercise Blood Lactate

Descriptive statistics for post exercise BL values recorded during the maximal incremental ramp tests and the constant load verification test are reported in Table 5. A one-way repeated measures ANOVA was performed to determine if there was a significant difference in post exercise BL across the three tests. Mauchly's test indicated that the assumption of sphericity had been maintained $\chi^2(2) = 0.92, p = 0.63$. The results show that BL was not significantly affected by the test being performed, $F(2,30) = 0.03, p = 0.97$.

Table 5

Descriptive statistics of BL values recorded during three maximal tests

	Minimum	Maximum	Mean	Standard Deviation
BL Test 1 (mM)	6.8	21.3	11.5	4.3
BL Test 2 (mM)	4.4	18.9	11.8	4.0
BL Verif (mM)	4.0	17.9	11.6	4.2

Note. BL = Post exercise blood lactate; Verif= Verification phase.

Maximum Rating of Perceived Exertion

Descriptive statistics for RPEmax reported during the maximal incremental ramp tests and the constant load verification test are reported in Table 6. A one-way repeated measures ANOVA was performed determine if there was a significant difference across the three tests. Mauchly's test indicated that the assumption of sphericity had been maintained $\chi^2(2) = 5.8, p > 0.05$. The results show that RPEmax was not significantly affected by the test being performed, $F(2,30) = 2.33, p > 0.05$.

Table 6

Descriptive statistics of RPEmax values recorded during three maximal tests

	Minimum	Maximum	Mean	Standard Deviation
RPEmax Test 1	18	20	19.4	0.73
RPEmax Test 2	17	20	19.4	0.89
RPEmax Verif	17	20	19.0	0.97

Note. RPEmax= Maximum rating of perceived exertion; Verif= Verification phase.

Peak Oxygen Consumption

Descriptive statistics for VO_2peak ($L \cdot min^{-1}$) during the maximal incremental ramp tests and the constant load verification test are presented in Table 7. A one-way repeated measures ANOVA was performed to determine if there was a significant difference across the three tests. Mauchly's test indicated that the assumption of sphericity had been violated $\chi^2(2) = 7.7, p < 0.01$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.7$). The results show that VO_2peak was not significantly affected by the test being performed, $F(1.41, 21.08) = 0.54, p > 0.05$.

Table 7

Descriptive statistics of VO_2peak values recorded during three maximal tests

	Minimum	Maximum	Mean	Standard Deviation
VO_2peak Test 1 ($L \cdot min^{-1}$)	1.73	4.32	2.78	0.77
VO_2peak Test 2 ($L \cdot min^{-1}$)	1.75	4.16	2.77	0.73
VO_2peak Verif ($L \cdot min^{-1}$)	1.90	4.07	2.74	0.69

Note. VO_2peak= Peak oxygen consumption; Verif= Verification phase.

Chapter 5

DISCUSSION

The purpose of this study was to determine whether a verification phase following a maximal GXT, where VO_2max had been thought to be measured, was necessary to confirm a true VO_2max in a collegiate non-athlete population. Previous research has indicated that currently established criteria for determination of true VO_2max do not apply across populations and protocols (Howley et al., 1995; Misquita et al., 2001; Rivera-Brown & Frontera, 1998). Therefore, confirmation of true VO_2max has been done using a verification phase following a GXT. If the VO_2peak from the GXT was reproduced during the verification phase then a true VO_2max was confirmed. However, the utility of a verification phase has been limited primarily to the male and/or athlete populations. Additionally, little to no research has been done to assess the necessity of a verification phase following a structured properly performed GXT in the collegiate population. This chapter discusses first VO_2max criteria and second the utility of a verification phase as each apply to the findings of this study.

VO_2max Criteria

VO_2 Plateau

The primary criterion used for establishing that VO_2max has been measured is a small or little increase in O_2 consumption with an increase in work rate (Midgley et al., 2006). Traditionally a VO_2 plateau is defined as an increase in VO_2 less than 150 $mL \cdot min^{-1}$ in response to an increase in workload (Taylor et al., 1955). In the current study it was observed that a VO_2 plateau was inconsistently achieved. Specifically, 37.5% of participants elicited a VO_2 plateau in both of the maximal tests, 68.75% of participants elicited a plateau during at least one of the two maximal tests, and 31.25% of participants did not elicit a VO_2 plateau during either of the maximal tests.

In the instance where a verification phase is performed following a maximal test Midgley and Carrol (2009a) have argued that a supramaximal verification phase is another way of fulfilling the plateau criterion. In short, if VO_2 increases less than 150 $mL{\cdot}min^{-1}$ from the final stage of the second maximal incremental ramp test to the end of the verification phase, then a plateau could be said to have occurred. If defined as such, then four of the remaining five participants that did not plateau during the maximal incremental ramp tests elicited a VO_2 plateau during the verification test in the current study. The question becomes is a verification phase necessary in the absence of a plateau during the maximal incremental ramp test in order to fulfill the plateau criterion? The results of the current study indicate that whether or not a plateau in VO_2 occurred mean VO_2peak did not differ significantly between tests. Therefore, it would appear that a verification phase is not necessary in the absence of a VO_2 plateau.

Previous research has reported various percentages of participants eliciting a VO_2 plateau during graded exercise testing as well (Day et al., 2003; Rossiter et al., 2006). The varying number of participants eliciting a plateau within the literature has been attributed to a number of different factors including: the population being tested, the modality used for testing, and the protocol employed to test (Howley et al., 1995). However, the definition of a plateau in VO_2 is the most inconsistent. Day and colleagues (2003) defined a plateau as simply seeing little to no further increase in VO_2, finding that only 17% of subjects tested exhibited a "plateaulike response." Byun-Kon Yoon, Kravitz, and Robergs (2007) defined a plateau as a slope of < 0.05 $L{\cdot}min^{-1}$ of the VO_2—time relationship during the final 30 seconds(s) of the continuous incremental test and found that depending on the sex of the subject and the protocol used, a varying number of subjects elicited a VO_2 plateau. Midgley and colleagues (2009b) examined the VO_2 plateau from a more traditional angle setting threshold values at 100, 150, and 200 $mL \cdot min^{-1}$ between workloads, finding that as the threshold value increased so did the number of participants who fulfilled the criterion.

The inconsistent achievement of a plateau shown in the current study and in previous research supports the conclusion that VO_2 plateau is a questionable primary criterion for determination of "true" VO_2max. By redefining the criterion, researchers have still found a varying number of subjects eliciting a plateau during maximal graded exercise tests (Day et al., 2003; Midgley et al., 2009b; Yoon et al., 2007). Therefore, the results of the current study indicate that the plateau criterion is not an acceptable criterion for determination of a "true" VO_2max.

Respiratory Exchange Ratio

In the absence of a VO_2plateau, RER has been one of the best secondary criterions to confirm a "true" VO_2max. RER increases in conjunction with the increase in ventilation that occurs towards max as the concentration of CO_2 increases. ACSM (2010) stated that an RER > 1.10 is indicative of a maximal effort however considerable interindividual variability can exist. In the current study, on average the subjects reached ACSM's (2010) criterion of an RER > 1.10 during both of the maximal incremental ramp tests. In fact, on average the subjects exceeded an RER > 1.15 which has been suggested as a more appropriate criterion during graded exercise tests using cycle ergometry (Howley et al., 1995; Midgley et al., 2009b). However, on average subjects did not achieve an RER > 1.10 during the verification phase of this study. In fact RER values during the verification phase were significantly less than during the maximal incremental ramp tests.

The findings of the current investigation are consistent with a previous study that allowed less than one hour between the incremental portion and verification phase of testing. Specifically, Rossiter and colleagues (2006) found RER values significantly lower during the verification phase after only five minutes of recovery following the incremental portion of testing. One limitation of this study may be that subjects were not given a long enough recovery period (10 minutes) following the second maximal incremental ramp test. A previous study reported maximal RER values significantly higher during the verification than the incremental test (Astorino, White, & Dalleck, 2009). Astorino and colleagues (2009) had subjects perform the verification phase at least one hour and up to 24 hours after completing the incremental portion of testing.

In addition to a limited recovery period, the length of the verification phase during the current study may have been a limiting factor as well. The average length of the verification phase during the current study was less than two minutes (111.06s). Previous studies have reported average supramaximal verification phase times anywhere from two to four minutes in length (Astorino et al., 2009; Midgley et al., 2009b; Foster et al., 2007). The supramaximal workload (one workload greater than the final stage of the continuous incremental test) at which participants performed the verification phase may have also been a limiting factor. Specifically, it may have been too difficult to complete which caused the verification phase to last less than two minutes on average. The narrow time frame of the verification phase in the current study may have limited lactate accumulation, preventing the production of an excess amount of CO_2 to drive ventilation. Carbon dioxide production (VCO_2) was not analyzed in the current study but the less than two minute verification phase may not have been long enough to get a great enough VCO_2 response to drive RER above 1.10.

Regardless of the limitations mentioned above, the purpose of the verification phase is not to reproduce fulfillment of VO_2max criteria. The purpose of the verification phase is to reproduce VO_2peak, which occurred in the current study. Therefore, despite limitations during the verification phase, RER appears to be a valid measure of maximal effort during a maximal incremental ramp test. However, the average RERmax in the current study was well above the accepted ACSM threshold criterion of > 1.10, indicating that the threshold criterion may be too low for this population when testing on a cycle ergometer.

Maximal Heart Rate

The second secondary criterion for determination of true VO_2max is maximal heart rate (HRmax). According to ACSM (2010) the criterion is defined as the failure of heart rate to increase in response to an increase in exercise intensity. However the majority of existing research defines the HRmax criteria as some set percentage of age predicted max heart rate (APMHR) using the equation 220 – age.

In the current study, when threshold criteria were set at reaching $\pm$ 10 bpm of APMHR, less than half of subjects fulfilled the criteria during both maximal incremental ramp tests as well during the verification phase. In fact average HRmax for all three tests did not achieve threshold criterion in terms of average age for the entire sample. However, HRmax did not differ significantly across the three separate tests. These results are consistent with the findings of Rossiter and colleagues (2006). Conversely, Astorino and colleagues (2009) reported significantly higher HRmax during the supramaximal verification exercise bouts.

The variability across studies is not unexpected. In general HRmax in terms of some set percentage of APMHR during maximal exercise testing is scrutinized due to a high intersubject variability that has been reported to have a 95% confidence interval as high as 45 bpm (Midgley et al., 2007). Previous research as well as this study evidence the need for reevaluation of HRmax as a criterion for determination of "true" VO_2max.

Post Exercise Blood Lactate

The third secondary criterion for confirmation of VO_2max is measurement of post exercise blood lactate concentration (BL). Blood lactic acid increases as more fast-twitch muscle fibers are recruited at maximal effort. In general threshold criteria for BL is set at > 8mM (ACSM, 2010). In the current study, average BL was > 8mM across the three exercise tests. Additionally, 81.25% of subjects on the three separate tests achieved a BL > 8mM. In terms of the maximal incremental ramp tests these results are consistent with the majority of the literature in this population (Duncan et al., 1997; Howley et al., 1995; Midgley et al., 2009b). Some researchers believe that there is a call for modality dependent criteria (Howley et al., 1995). Midgley and colleagues (2009b) found that BL was significantly higher on the cycle ergometer (Mean (SD) = 8.3 (2.0)) vs. the treadmill (Mean (SD) = 11.5 (1.2)) when testing competitive cyclists and runners. Howley and colleagues (1995) suggests that the threshold value of > 8mM established in the 1950s (Astrand, 1952) may in fact be too low.

Previous research has not reported BL values following a verification phase. The results of this study indicate that subjects achieved threshold criteria for BL during the verification phase and that BL did not differ significantly across the three tests. However, as Howley and colleagues (1995) suggested the threshold criterion may be set too low for cycle ergometry max testing. This was evidenced by the work of Midgley and colleagues (2009b) as well as in this current study calling for better modality specific criteria.

Rating of Perceived Exertion

The final secondary criterion for determination of a "true" VO_2max is RPE. As the newest of the secondary criterion, limited research has been done assessing it as a valid measure for determination of VO_2max. ACSM (2010) has established that an RPE > 17 on BORG's 6 – 20 scale constitutes a "maximal" effort. The results of this study show that average RPE across the three tests was > 17. Additionally, RPE did not differ significantly between the three tests. These results are consistent with the study by Benson and Swensen (2007) performed on a similar population that reported an average RPE at max as 17.7. Despite the scrutiny placed on the measure as being "one-dimensional," RPE appeared to consistently measure exertion between the three tests performed in the current study.

Verification Phase

The results from the current study indicate that many of the established criteria for determining if VO_2max has been measured on a cycle ergometer in the collegiate non-athlete population appear to be inadequate. These findings are consistent with previous research in varying populations (Midgley et al., 2009b; Poole et al., 2008; Rivera-Brown & Frontera, 1998; Snell et al., 2007). The recently popular, proposed answer to this problem is the verification phase. If VO_2peak is reproduced or does not increase beyond 150 ml·min^{-1} during the verification phase then "true" VO_2max has been measured (Midgley & Carrol, 2009a).

In the current study VO_2peak was measured during two incremental tests as well as during a verification phase. VO_2peak did not differ significantly across these three tests, confirming the main hypothesis of this study. These findings are consistent with previous research that utilized a verification phase following an incremental test. Poole and colleagues (2008) found that despite subjects not fulfilling many of the established criteria during the incremental tests, VO_2peak did not differ significantly ($p < .05$) between the incremental (4.03 ± 0.1 L·min^{-1}) and verification phases (3.95 ± 0.1 L·min^{-1}). Similar results have been seen in competitive male athletes, healthy males varying in age from 19-61, active healthy males in their 30s, sedentary men and women, and female university cross-country runners (Astorino et al., 2009; Day et al., 2003; Foster et al., 2007; Midgley et al., 2009b; Poole et al., 2009; Rossiter et al., 2006).

The current study aimed to evaluate the utility of a verification phase in a recreationally active non-athlete college population. Correct measurement of VO_2max is important when interpreting the results of these studies when repeated measurements of VO_2max are used to evaluate variables such as training effect. Midgley and Carrol (2009a), advocates of the verification phase for confirmation of "true" VO_2max," have noted that not performing a verification phase could be time efficient and would not place the subject under any additional unnecessary stress.

In contrast, the results of this study indicate that when performing graded exercise testing for evaluation of VO_2max in a practiced university setting adding a verification phase would waste both time and place subjects under unnecessary stress. Testing took place on two separate days and yet the researchers would have found VO_2max values that were not statistically different irrespective of whether a verification phase was performed or not.

Summary

The current study found that VO_2peak did not differ significantly between two maximal incremental ramp tests and a constant load verification test, which indicates that a verification phase would not be necessary to confirm VO_2max in this population. In terms of currently established criteria, the results of the current study call for reevaluation of the currently established criteria for determining if "true" VO_2max has been measured.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study examined whether a verification phase following a continuous incremental GXT in a collegiate non-athlete population, in which VO_2max was being measured, was necessary to confirm that a "true" VO_2max had been measured. Sixteen (8 male, 8 female), non-athlete Ithaca College Anatomy and Physiology students participated in the repeated measures design study. Each subject was tested on two separate days approximately 48 hours apart. On the first day of testing subjects completed a continuous incremental maximal GXT on a cycle ergometer to volitional exhaustion. Throughout the GXT VO_2 and RER were continuously monitored via direct spirometry, and HR was continuously monitored by a heart rate monitor. RPE was taken during the final 30s of each two-minute stage. Five minutes after terminating the test a small blood sample was taken for BL analysis.

Approximately 48 hours later each subject returned to the laboratory and completed a second continuous incremental maximal GXT following the same procedures described for the first test with one exception. After terminating the test subjects completed a 10-minute active recovery. During active recovery BL was assessed via blood sample at the halfway point. After active recovery was completed each subject completed a constant load verification phase to exhaustion at one workload greater than the final workload (where at least one minute had been completed) achieved during the GXT on that day. VO_2, RER, and HR were continuously monitored throughout and RPE was taken at the end of the test. Five minutes after termination BL was assessed a final time.

VO_2peak, RER, HRmax, BL, and RPEmax were statistically analyzed with a one-way repeated measures ANOVA. VO_2peak, HRmax, BL, and RPEmax did not differ significantly between the three tests. RER did differ significantly between the continuous incremental tests and the verification phase. These findings suggest that a verification phase following a maximal incremental ramp test is not necessary to confirm VO_2max.

Conclusions

Results of this study support the following conclusions:

1. VO_2max does not differ statistically between a continuous incremental max GXT that does not have a verification phase and one that does.
2. HRmax, BL, and RPE do not differ statistically between a continuous incremental max GXT and a verification phase.
3. Established VO_2max criterion (VO_2plateau; RER > 1.10; HRmax $\pm$ 10bpm; BL $>$ 8mM; RPE >17) are not consistently met during graded exercise testing.

Recommendations

The following recommendations for future study are to:

1. Examine the necessity of a verification phase on alternative populations.
2. Examine the timing of the verification phase and whether the timing of testing has a significant effect on the variables measured.
3. Examine the length of the verification phase and the influence the length of the test has on VCO_2 kinetics.

REFERENCES

American College of Sports Medicine. (2010). *ACSM's guidelines for exercise testing and prescription*. Philadelphia: Lippincott Williams & Wilkins.

Astrand, P.O. (1952). *Experimental studies of physical working capacity in relation to sex and age*. Copenhagen: Ejinar Munksgaard.

Astorino, T.A., White, A.C., & Dalleck, L.C. (2009). Supramaximal testing to confirm attainment of VO_2max in sedentary men and women. *International Journal of Sports Medicine, 30*, 279-284.

Benson, A., & Swensen, T. (2007). Criteria for maximal oxygen uptake in collegiate subjects. (Unpublished data). Ithaca College, Ithaca, NY.

Borg, G.A. (1974). Perceived Exertion. *Exercise and Sport Science Review, 2*, 131-153.

Day, J.R., Rossiter, H.B., Coats, E.M., Skasick, A., & Whipp, B.J. (2003). The maximally attainable VO_2 during exercise in humans: The peak vs. maximum issue. *Journal of Applied Physiology, 95*, 1901-1907.

Duncan, G.E., Howley, E.T., & Johnson, B.N. (1997). Applicabilty of VO_2max criteria: Discontinuous versus continuous protocols. *Medicine and Science in Sports and Exercise, 29*(2), 273-278.

Foster, C., Kuffel, E., Bradley, N., Battista, R.A., Wright, G., Porcari, J.P., Lucia, A., & deKoning, J.J. (2007). VO_2max during successive maximal efforts. *European Journal of Applied Physiology, 102*, 67-72.

Hagberg, J.M., Giese, M.D., & Schneider, R.B. (1978). Comparison of the three procedures for measuring VO_2 max in competitive cyclists. *European Journal of Applied Physiology, 39*, 47-52.

Hill, A.V. & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly Journal of Medicine, 16*, 135-171.

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

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

McArdle, W.D., Katch, F.I., & Pechar, G.S. (1973). Comparison of continuous and discontinous treadmill and bicycle tests for max VO_2. *Medicine and Science in Sports, 5*(3), 156-160.

Midgley, A.W., & Carroll, S. (2009a). Emergence of the verification phase procedure for confirming 'true' VO_2max. *Scandinavian Journal of Medicine & Science in Sports, 19*, 313-322.

Midgley, A.W., Carroll, S., Marchant, D., McNaughton, L.R., & Siegler, J. (2009b). Evaluation of true maximal oxygen uptake based on a novel set of standardized criteria. *Applied Physiology, Nutrition, and Metabolism, 34*, 115-123.

Midgley, A.W., McNaughton, L.R., & Carroll, S. (2006). Verification phase as a useful tool in the determination of the maximal oxygen uptake of distance runners. *Applied Physiology, Nutrition, and Metabolism, 31*, 541-548.

Midgley, A.W., McNaughton, L.R., Polman, R., & Marchant, D. (2007). Criteria for determination of maximal oxygen uptake: A brief critique and recommendations for future research. *Sports Medicine, 37*(12), 1019-1028.

Misquita, N.A., Davis, D.C., Dobrovolny, C.L., Ryan, A.S., Dennis, K.E., & Nicklas, B.J. (2001). Applicability of maximal oxygen consumption criteria in obese, postmenopausal women. *Journal of Women's Health & Gender-Based Medicine, 10*(9), 879-885.

Myers, J., Walsh, D., Sullivan, M., & Froelicher, V. (1990). Effect of sampling on variability and plateau in oxygen uptake. *Journal of Applied Physiology, 68*(1), 404-410.

Noakes, T.D. (1988). Implications of exercise testing for prediction of athletic performance: A contemporary perspective. *Medicine and Science in Sports and Exercise, 20*(4), 319-330.

Poole, D.C., Wilkerson, D.P., & Jones, A.M. (2008). Validity of criteria for establishing maximal O_2 uptake during ramp exercise tests. *European Journal of Applied Physiology, 102*, 403-410.

Rivera-Brown, A.M., & Frontera, W.R. (1998). Achievement of plateau and reliability of VO_2max in trained adolescents tested with different ergometers. *Pediatric Exercise Science, 10*, 164-175.

Rossiter, H.B., Kowalchuck, J.M., & Whipp, B.J. (2006). A test to establish maximum O_2 uptake despite no plateau in the O_2 uptake response to ramp incremental exercise. *Journal of Applied Physiology, 100*, 764-770.

Snell, P.G., Stray-Gundersen, J., Levine, B.D., Hawkins, M.N., & Ravens, P.B. (2007). Maximal oxygen uptake as a parametric measure of cardiorespiratory capacity. *Medicine and Science in Sports and Exercise, 39*(1), 103-107.

Tanaka, H., Monahan, K.D., & Seals, D.R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology, 37*(1), 153-156.

Taylor, H.L., Buskirk, E., & Henschel, A. (1955). Maximal oxygen intake as an objective measure of cardio-respiratory performance. *Journal of Applied Physiology, 8*(1), 73-80.

Thoden, J.S., MacDougall, J.D., & Wilson, B.A. (1982). *Testing aerobic power*. Ithaca, NY: Movement Publications, Inc.

Yoon, B.L., Kravitz, L. & Robergs, R. (2007). VO_2max, protocol duration, and the VO_2 plateau. *Medicine and Science in Sports and Exercise, 39*(7), 1186-1192.

APPENDIX A

Informed Consent Form

Comparison of VO_2max elicited from continuous GXTs and a constant-load test.

1. **Purpose of the Study:** The purpose of this study is to compare the amount of oxygen consumed at the point of fatigue during two continuous graded exercise tests (GXT) to the amount consumed at fatigue during one constant load tests. Secondly, the study aims to determine whether a constant load test is required to confirm a true VO_2max.

2. **Benefits:** You may benefit from participating in this study because you will learn what your maximum oxygen consumption is. You will also get firsthand experience on how scientific data is collected and receive extra credit. Your participation will also benefit the graduate student, who is learning how to conduct a scientific study. Last, it is hoped that the data generated will benefit the scientific community.

3. **Your Participation Requires** you to be at least 18 years old and able to exercise to exhaustion while cycling on a bike on 3 separate tests on 2 days separated by approximately 2 days. On the first day you will perform an incremental GXT. On the second day you will complete a second GXT followed by a constant load test after 10 minutes of rest.

Prior to each test, you will be weighed and then fitted with a chest strap so I can measure your heart rate. You will then warm up at an easy cycling pace for five minutes on the bike. Upon completion of the warm-up, you will be fitted with a nose clip and a headgear that will hold a mouth-piece attached to a hose from which your expired gases will be measured. For the GXT, you will be asked to maintain a speed of 80 repetitions per minute (rpm). Your bike test will begin with an easy resistance for 2 minutes and then every 2 min thereafter the resistance will increase making it harder to maintain 80 rpms. The GXT will terminate when you feel you can no longer continue or you are unable to maintain 80 rpms. Immediately following termination, the headgear and nose clip will be removed and you will cool down by cycling comfortably on the cycle ergometer for 5 min. Five minutes into your cool down one of your fingertips will be sterilized with an alcohol prep pad. A small puncture will then be made in the sterilized fingertip with a sterile lancet so a small blood sample can be obtained. After the blood sample is taken you will be done for the day.

Approximately 2 days later you will return to the laboratory once again and complete a second GXT on the bike. The test will follow the same procedures as described above. The only difference is that immediately following termination, the headgear and nose clip will be removed and you will begin a 10-minute active recovery, where you will cycle on the bike at an easy pace. Five minutes into your active recovery one of your fingertips will be sterilized and another small blood sample will be taken in the same fashion as the first day of testing.

Once the 10-minute active recovery is completed you will be prepped for the constant load test. Once again you will be fitted with a nose clip and a headgear that is attached via a hose to the metabolic cart for gas measurements. The resistance for the constant-load cycle test will be set at a resistance level higher than that which was obtained during the final 2 minutes of the GXT. You will be encouraged to cycle until you no longer feel you can continue and then the test will be terminated. Immediately following termination, the headgear and nose clip will be removed and you will cool down by cycling comfortably on the bike for 5 min. At this point one final blood sample will be taken for analysis via the same method used at the two previous time points.

Total participation time for both testing days is about 1.5 hr. After the study is completed, I will provide you with your results and an explanation.

4. **Risks of Participation:** The risks associated with the VO_2max test include skeletal muscle injury and possibly a cardiac event, which could be fatal. In your age group, the risk of a cardiac event is between 0.75 and 0.13 per 100,000 training sessions. You may also have sore muscles 24 to 48 hours after the test; the fingertip that is lanced may also be tender for a few days. To minimize the risks, you will warm-up and cool-down before and after each test. During this time your heart rate will constantly be monitored. In the case of abnormal heart rate response to exercise you will not be allowed to continue. If you feel poorly during either test, you may terminate it at any time. In the event that there is an injury or cardiac event, standard first aid procedures will be promptly administered. I am CPR and First Aid certified. A cellular phone will be present during all tests and a call will be made to 911 to seek additional assistance if warranted.

5. **Compensation for Injury:** If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If you have insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

6. **If you would like more information** about this study at any time prior to, during, or following the data collection, you may contact Sarah Simunovich at ssimuno1@ithaca.edu or (408) 504-7888.

7. **Withdrawal from the study:** Participation in this study is voluntary and you may withdraw at any time if you so choose. You will not be penalized for withdrawing and will still be eligible for extra credit.

8. **Confidentiality:** Confidentiality is guaranteed for all participants. All data will be kept and stored in the Exercise and Sport's Science Department at Ithaca College. If you wish to be included in any popular publications stemming from this work you will have the opportunity to allow your data to be printed in connection with your name.
I have read the above and I understand its contents. I agree to participate in the study.

I acknowledge that I am of 18 years or older.

________________________________   ______________________________

Your Name (please print)   Your Signature

APPENDIX B
Medical Health History

ID #: ____

Age: __________ Weight: __________ Sex: ______________

Medical/Health History (please check all that apply)
[ ] Heart/Disease [ ] Lung Disease
[ ] Stroke [ ] Diabetes
[ ] Heart Murmur [ ] Epilepsy
[ ] Skipped, rapid or irregular heart rhythms [ ] Injuries to back, hips, knees, ankles, or feet
[ ] High Blood Pressure
[ ] High Cholesterol
[ ] Rheumatic Fever
[ ] Other conditions/comments: (please explain)

Present Symptoms (please check all that have applied within the last **six months**)
[ ] Chest pain [ ] Ankle/Leg Swelling
[ ] Shortness of Breath [ ] Joint/muscle injury requiring medical attention
[ ] Lightheadedness [ ] Allergies (if yes, please list)
[ ] Heart Palpitations
[ ] Loss of consciousness
[ ] Illness, surgery, or hospitalization
[ ] Other conditions/comments: (please explain)

Current medications (please list all medications presently being taken)

Exercise Habits
Do you presently engage in physical activity? [ ] Yes [ ] No
If so, what type of exercise? [ ] Aerobic [ ] Strength Training [ ] Both
How hard do you exercise? [ ] Easy [ ] Moderate [ ] Hard
How many times a week do you work out on average? __________
How many times a day do you work out on average? __________
Have you ever had any discomfort, shortness of breath, or pain while exercising?

[ ] Yes [ ] No

APPENDIX C

Pre-test Instructions

Test Date: ___________________________ Test Time: ________________

You are scheduled to complete a maximum effort exercise test. Your performance depends upon the adherence of these instructions:

1. Do not perform heavy exercise in the 24 hours preceding the test.
2. Do not drink alcohol for 12 hours preceding the test.
3. Do not use stimulants such as caffeine (e.g. coffee) or nicotine (i.e. cigarettes) for three hours preceding the test
4. Do not eat for three hours preceding the test.
5. Do not eat any food that may cause you discomfort the day of the test.
6. Avoid over-the-counter medications for the 12 hours preceding the test. (However, cancel the appointment if you are ill and treat yourself accordingly; we can always reschedule)
7. Wear comfortable clothing and appropriate shoes during the test. (i.e. shorts, t-shirt, and sneakers are recommended)
8. Please, sustain your same lifestyle habits (eating, exercise, medication, etc.) between tests.

We thank you for your cooperation!

APPENDIX D
24-Hour Health History Form

Name: ______________________________ Date: __________

Current Health Status (please check all that apply)
[ ] Nausea [ ] Sore Throat [ ]
Headache
[ ] Body Ache [ ] Chills [ ]
Lethargy
[ ] Nasal Drip [ ] Cramping [ ]
Muscle Aches
[ ] Chest Pain [ ] Shortness of Breath [ ]
Dizziness

If female, date of last period ______________________________

Diet

Have you consumed alcohol in the last 12 hours? [ ] Yes [ ] No

Have you used caffeine or nicotine in the last three hours? [ ] Yes [ ] No

Did you eat any food in the last three hours? [ ] Yes [ ] No

If so, please list:

Has your diet changed drastically since the last exercise test? [ ] Yes
[ ] No

If so, please describe:

Exercise

Have you exercised in the last 24 hours? [ ] Yes
[ ] No

If so, please describe:

Has your exercise routine changed at all since the last test? [ ] Yes [ ] No

If so, please explain:

Over-the-Counter and/or Prescription Drug Use

Have you taken any over the counter drugs (e.g., cold meds) in the last 24 hours?

[ ] Yes [ ] No

Has there been any change in your use of prescription drugs? [ ] Yes
[ ] No

If so, please explain:

Injury

Have you experienced any physical pain in the last 24 hours? [ ] Yes
[ ] No

If so, please explain:

Is there any physical injury we should know about before you perform the test?

[ ] Yes [ ] No

If so, please explain:

Sleep Pattern:

Has your sleep pattern changed since the last exercise test? [ ] Yes [ ] No

Do you feel drowsy, tired, or run down at this time? [ ] Yes [ ] No

If so, please describe:

Has there been any change since the last exercise test that you feel could compromise your performance on today's exercise test? [ ]
Yes [ ] No

If so, explain:

Other questions/comments/concerns please state below.

APPENDIX E

Data Sheet

Date: _______ Time: _______ Technician_______ Test: _______

Name: ___________________________ ID#:__________ Age:________

Sex: ___________ Height: ___________ Weight: ___________

Day 1

Initial Speed/Load: ______________________ **Stage Length:** _________________

Stage	Grade/Load	HR	RPE	RER	VO_2
Warm-Up					
1					
2					
3					
4					
5					
6					
7					
8					

Final Speed/Load: ___________ **Final Grade:** ___________ **VO_2max:** _______

Post Blood Lactate: ___________ **Final RER:** ___________ **Final RPE:** _______

Comments:

Day 2

Date: ___________ Time: ___________ Technician___________

Test: ___________ Height: ___________ Weight: ___________

Initial Speed/Load: ______________________ **Stage Length:**____________

Stage	Grade/Load	HR	RPE	RER	VO_2
Warm-Up					
1					
2					
3					
4					
5					
6					
7					
8					

Final Speed/Load: ___________ **Final Grade:** ___________ **VO_2max**: ________

Post Blood Lactate: ___________ **Final RER:** ___________ **Final RPE:** _______

Verification Phase

Speed: _______ **Load/Grade:** _______ **Time of Test:** _________

Post Blood Lactate: ___________ **VO_2max**: ___________ **Final RER:** _______

Comments: