

To the Graduate Council:

I am submitting herewith a thesis written by James P. Ford entitled "The effects of stage duration on achieving a plateau in oxygen uptake during a maximal exercise test." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sports Studies.

Edward T. Howley

Edward T. Howley, Major Professor

We have read this thesis
and recommend its acceptance:

David R. Bassett, Jr.

Dr. L. J.

Accepted for the Council:

Lawminkel

Associate Vice Chancellor and
Dean of the graduate School

THE EFFECTS OF STAGE DURATION
ON ACHIEVING A PLATEAU IN OXYGEN
UPTAKE DURING A MAXIMAL EXERCISE TEST

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

James P. Ford
August 1999

Dedication

To my parents, for their love, guidance, and never ending support. Thanks so much for always being there.

To Kristin, you're the reason I'll never second-guess my decision to become a Southerner.

I Love You All.

Acknowledgements

I would like to thank Dr. Edward T. Howley for the time and energy he dedicated to this project, and for being a role model to aspire to. I would also like to thank Drs. Dixie L. Thompson, and David Bassett, Jr. for serving on my graduate committee. Special thanks goes out to all the subjects who participated in the study, I know it wasn't a pleasant experience. I would like to thank Jason Langley for his help in the lab and dedication to the project.

All others who helped with the project I am forever grateful.

-----Thank you very much

Abstract

This investigation examined whether the length of stage during a GXT could influence the occurrence of a plateau in $\dot{V}O_2$. Ten males between the ages of 18 and 45 volunteered to participate in the study. They each completed a Physical Activity Readiness Questionnaire and an informed consent form. Each participant completed four graded exercise tests to exhaustion on the treadmill. The first test was used to obtain the subject's maximal heart rate, so the speed of the treadmill for the three subsequent tests could be set at 80% of their maximal heart rate. All tests were performed within a two-week period for each subject with no tests performed on consecutive days. During the tests the subjects ran on the treadmill at a constant speed while the grade of the treadmill was increased every 30, 60, or 90 seconds depending on the protocol. While running on the treadmill expired air was analyzed using an automated metabolic system. Upon completion of each test a small blood sample was obtained and used to determine post-exercise lactate concentration. The analysis of variance showed significant differences between grade at exhaustion and time to exhaustion between all three protocols. A significant difference in RER and post-exercise lactate was observed between the 30 and 60-second protocols and the 30 and 90-second protocols, ($p < .001$) and ($p < .05$) respectively, with no differences between the 60 and the 90-second protocols. Additionally, no significant differences were found for $\dot{V}O_{2max}$, or plateau attainment when the three treatments were compared. The data show that shorter duration GXT's will elicit higher RER values and higher post-exercise lactate values.

Table of Contents

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF LITERATURE	4
Maximal Oxygen Uptake	4
Variability among maximal oxygen uptake values	
Factors limiting maximal oxygen uptake	
Cardiac Output	
Peripheral Circulation	
Metabolic Capacity of the Muscle	
Pulmonary Diffusion Capacity for Oxygen	
Effect of Test Protocol on the Measurement of $\dot{V}O_{2\max}$	11
Continuous vs. discontinuous	
Mode of Exercise: Cycle vs. Treadmill	
Treadmill GXT's	
Grade vs. speed	
Test duration	
Other factors to consider	
Summary	
Criteria for Having Achieved $\dot{V}O_{2\max}$	18
Plateau in oxygen uptake	
Heart rate	
Post-exercise lactate	
RER	
Conclusion	26
III. METHODS	27
Baseline Data	27
Tests for Maximum Heart Rate	28
Tests for $\dot{V}O_{2\max}$	28
Statistical Analysis	30
IV. RESULTS	31
V. DISCUSSION	33
Conclusion	41
Recommendations for Further Study	41

	vi
LIST OF REFERENCES	43
APPENDICES	51
Appendix A	52
Appendix B	54
Appendix C	57
Appendix D	59
VITA	61

Chapter I

Introduction

Maximal oxygen uptake ($\dot{V}O_{2\max}$) is one of the most common measurements made in exercise physiology laboratories and clinical testing facilities. $\dot{V}O_{2\max}$ is viewed as the best measure of cardiorespiratory fitness (1, 5, 57, 62) and is clearly linked to the capacity for success in endurance performances (1, 5). $\dot{V}O_{2\max}$ is typically measured during a maximal graded exercise test, performed in either a continuous (10, 22, 29, 43) or discontinuous (20, 40, 42, 70) manner. These tests require the subject to exercise to the point of volitional exhaustion, but some subjects may quit before achieving the highest rate of oxygen consumption due to muscle pain, cramping, or lack of motivation. Investigators hope that such is not the case, and a variety of criteria have emerged over time to confirm that the subject had given a maximal effort.

The first and primary criterion used to confirm a maximal effort is the presence of a plateau in oxygen uptake in the last minutes of an incremental test. Sometimes a subject can continue to exercise for a minute or so after oxygen uptake has reached its highest value. As a result, a "plateau" in oxygen uptake may occur—meaning that the oxygen uptake did not increase when the exercise intensity is increased. Investigators reasoned that this was firm evidence that the subject had reached his/her $\dot{V}O_{2\max}$. The problem with this criterion is that investigators differ on what is considered a valid plateau (1, 16, 25, 32, 45, 66, 67, 70). Nevertheless, no matter which definition is used, not all subjects will achieve a plateau (14-17, 26, 35, 45, 66, 70). Consequently, investigators tried to identify other variables that would indicate that the subject was

working maximally when the highest oxygen uptake was measured. These variables included the heart rate achieved during the graded exercise test (GXT), the post-exercise blood lactate concentration, and the magnitude of the ratio of carbon dioxide production ($\dot{V}\text{CO}_2$) to oxygen uptake ($\dot{V}\text{O}_2$), the respiratory exchange ratio (RER).

Although few would argue that achieving maximal heart rate during a GXT is indicative of a maximal effort (14, 25), the "standard" to which the measured value is compared is so variable (standard deviation of estimate = ± 10 b/min) as to render this "standard" questionable at best (14). In contrast, an elevated post-exercise blood lactate concentration indicates that the subject had worked at an intensity causing glycolysis to be activated substantially, suggesting great effort (2, 3, 20, 62). A variety of post-exercise blood lactate concentrations (e.g., 8-10 mM) have been recommended as standards (5, 14, 20, 67). The RER is an indirect estimate of the change in the blood lactate concentration, since the buffering of the lactic acid generates CO_2 . A variety of RER standards (e.g., 1.02 (47), 1.10 (25, 44) and 1.15 (20, 34)) have been recommended, but the range of values make such "standards" problematic. In addition, some subjects who achieve the plateau standard may not demonstrate an extreme RER response (14, 16).

The latter two standards suggest that there is a link between a high level of glycolysis and performance of a maximal effort. The ability of an individual to continue exercising during a graded exercise test past the point at which the oxygen uptake is near the subject's maximal value would require an ability to incur a large oxygen deficit. In fact, the larger the maximal accumulative oxygen deficit, the greater is the ability of the individual to do tasks requiring energy expenditures in

excess of the capacity of oxidative phosphorylation to provide ATP (3). This ability to incur an oxygen deficit may be linked to the achievement of a plateau in oxygen uptake during a GXT. Myers has suggested that variables such as work increments and the sampling frequency during a graded exercise test can affect the occurrence of a plateau in $\dot{V}O_2$ (47).

The present study is based on Myer's hypothesis that the demonstration of a plateau might be affected by the test protocol itself. It is possible that stage duration may have an effect on an individual's attainment of a plateau. Theoretically, by shortening the length of each stage (time at a particular grade), there would be a greater chance of demonstrating the plateau. Short stage durations would shorten the total amount of time the subject spends running on the treadmill. It is possible that the shorter the stage duration, the more anaerobic energy the individual will have reserved to endure the GXT at additionally greater workloads without an increase in oxygen uptake. We hypothesize that the manipulation of the stage duration of a GXT will have an effect on the occurrence of a plateau. The longer the stage duration is in a GXT, the less likely it is that a plateau will occur, while the shortest stage duration will more likely elicit a plateau in oxygen uptake.

Chapter II

Review of Literature

The purpose of this study was to examine the effect that varying the stage length of a maximal graded exercise test has on the occurrence of a plateau in oxygen uptake. The review of literature examines such topics as the definition of maximal oxygen uptake, the factors limiting maximal oxygen uptake, factors affecting the measurement of $\dot{V}O_{2\max}$, and the criteria for having achieved $\dot{V}O_{2\max}$.

Maximal Oxygen Uptake

Maximal oxygen uptake is one of the most common variables measured in an exercise setting. It is viewed as the best measure of cardiorespiratory fitness (1, 5, 57, 62) and is clearly linked to the capacity for success in endurance performances (1, 5). Costill and colleagues showed this link by reporting a relationship ($r = -0.91$) between $\dot{V}O_{2\max}$ and time for a 10 mile run in runners with a wide range of $\dot{V}O_{2\max}$ values (12).

The definition of maximal oxygen uptake has evolved throughout the years. It has been described as the maximal rate of energy output by combustion within the body (5) and maximal motor power by aerobic processes (62). However, Armstrong provides a more modern definition of maximal oxygen uptake when he states that it is the highest rate at which an individual can consume oxygen during heavy work; it limits the capacity to perform aerobic exercise; and is recognized as the best indicator of aerobic fitness (1). As exercise intensity increases so does oxygen uptake until a point is reached where no further increase in oxygen uptake occurs, even though the

subject is able to continue to increase his/her intensity (1). This latter statement by Armstrong is regarded as the "classic" definition of $\dot{V}O_{2\max}$.

Variability among maximal oxygen uptake values

One of the main focuses in the literature regarding maximal oxygen uptake is its repeatability. " $\dot{V}O_{2\max}$ is a stable and highly reproducible characteristic of an individual such as height and weight, but like weight it is subject to variation under certain conditions" (57). Scientists have sought to determine what might cause an individual's measured value to be different on two separate occasions.

There are three sources of error to consider when measuring maximal oxygen uptake. Assuming that environmental conditions are held constant on the days of testing, the sources of variability can be traced to three factors, 1) the biovariability of the subject, 2) measurement error, and 3) technological error.

In an early study of 30 subjects, Taylor found that intraindividual variation accounted for 10 to 58% of the total variance in $\dot{V}O_{2\max}$ (69). More recently, many investigators agree that in a well-performed direct measurement of maximal oxygen uptake the intraindividual variation is between 4 and 6% (total variation) (6, 16, 27, 35, 70, 74), with biological variability accounting for 90% of this total (35). In an effort to explain why an individual subject achieves different values on different days, Katch et al. state that this is reflective of the inherent biological variation of the organism (35).

Investigators have also explored the effect of time of day on $\dot{V}O_{2\max}$. For example, Wojtczak-Jaroszowa and Banaskiewicz (73) reported that the directly

measured $\dot{V}O_{2\max}$ was 5% greater in the morning compared with evening, and Yamaji et al. (75) found values to be 3% higher at 6 P.M. Conversely, others have found no circadian rhythm effect for maximal oxygen uptake (24, 53, 54).

Katch and colleagues state that some of the variability in $\dot{V}O_{2\max}$ for the same subject is due to technological error (35). The technological error is related to the accuracy with which pulmonary ventilation and the gas fractions can be measured, and the matching of the ventilation volume and gas fractions (in time) used to calculate $\dot{V}O_2$. During a GXT, one extra breath or one less breath, can increase the variation between trials. This can occur using a Douglas Bag (the classical method of gas collection) or a metabolic cart. The benefit of the Douglas Bag is that the gas volumes and the gas fractions are contained within the bag, so the fractions can easily be matched to the volume, while the metabolic cart can mismatch the volumes and gas fractions. A potential problem with metabolic carts is the time delay between when the breath is expired and when the gases in that breath are actually analyzed. This is of special concern during short increment GXT's.

Taylor found that technological error accounted for less than 1% of the total variability (69). In contrast, Cotes and Woolmer state that technological errors usually account for at least 10% of the total error (4-6%) and problems of gas analysis can give rise to large unsuspected systematic errors (13). McConnell endorses the use of automated systems as he explains that it will reduce errors due to leaky bags or faulty valves. Also, the investigator can continually monitor the progress of the test, preventing the need for retesting (43).

Factors limiting maximal oxygen uptake

There are several hypotheses proposing factors that limit oxygen uptake as $\dot{V}O_{2\max}$ is approached. These hypotheses include maximal cardiac output, the peripheral circulation, the metabolic capacity of skeletal muscle, and the pulmonary diffusion capacity for O_2 .

Cardiac output

Some researchers feel that the cardiovascular system is the limiting factor. Rowell states that the establishment of maximal oxygen uptake requires that a sufficient fraction of the total muscle mass be utilized during exercise to ensure that $\dot{V}O_{2\max}$ is limited by the capabilities of the cardiovascular system (57). A main example in the literature that shows the cardiovascular system to be a limiting factor of maximal oxygen uptake is the experiments analyzing the effects of active muscle mass on maximal oxygen uptake. It has been demonstrated that, in large muscle group activity, the capacity of the muscles to vasodilate (accept blood flow) exceeds the cardiac output of the heart. In contrast, exercise performed using smaller muscle masses is limited by the vasodilation capacity of the working muscle and not cardiac output (61). This fact is demonstrated in experiments that involve the comparison of arm exercise and leg exercise. Researchers found that maximal arm-work alone elicited about 65-75% of maximal oxygen uptake values of maximal leg-work performed alone (55). One would then think that if arm and leg-work were combined a much greater value for maximal oxygen uptake would be achieved than the value for either alone. However, this was not the case. Combined arm and leg work resulted in

similar $\dot{V}O_{2\max}$ values as leg-work alone (28, 48, 55). Also, superimposing arm-work on high intensity leg-work reduced blood flow to the legs, thus decreasing oxygen uptake in the legs (65). This shows that cardiac output was not able to support the work being performed by the legs when the arms were added. Vasoconstriction in the legs had to occur in order to maintain arterial pressure.

In Shephard's 1984 paper he is sure that the circulatory system is the limiting factor, but is not sure in what way. He states that that oxygen uptake may be limited by the circulatory system's inability to produce an adequate stroke volume, thus an inadequate cardiac output, or it may stem from a deficiency in venous return due to the building peripheral resistance (66). Also, Shephard points out that coronary perfusion is diminished by the relative shortening in the diastolic phase of the cardiac cycle (66).

Peripheral circulation

Åstrand and Saltin's 1961 paper discussed the factors limiting O_2 transport from air to tissue. One of the investigators hypothesized that a peripheral factor sets the limit, for example, the vascular bed in the working muscles or venous return to the heart (4). It is apparent that with training the capillaries in the muscle bed become more numerous; this increases the capacity for oxygen delivery, and decreases diffusion distance from the vessel to the mitochondria (37, 63). So it is thought that the capillary density of the muscle bed can limit maximal oxygen uptake. The one-leg versus two-leg experiments refute this hypothesis (38). In these experiments the $\dot{V}O_{2\max}$ of one-leg exercise was determined, and it was thought that when another leg was added to the exercise the $\dot{V}O_{2\max}$ of the active leg would be maintained. Instead,

Klausen et al. found that adding more muscle mass, and consequently more capillary density, actually decreased the $\dot{V}O_{2\max}$ of the leg (38) in order to maintain blood pressure. This is more evidence that overall maximal oxygen uptake is limited by maximal cardiac output and not factors present in the periphery.

Another way in which peripheral circulation was thought to limit $\dot{V}O_{2\max}$ is blood flow to non-exercising regions of the body, e.g., splanchnic flow (58). This blood flow "away" from the exercising muscle obviously limits the blood flow that could be perfusing the working muscle, thus limiting the oxygen consumption that the working muscles could attain if all blood flow was directed their way. This concept was refuted due to the fact that reduction in splanchnic blood flow during exercise is comparable in those that are trained and untrained (58).

Metabolic capacity of the muscle

It has been shown that endurance training increases the amount of mitochondria and oxidative enzymes within the active muscle, thus increasing the respiratory capacity of the muscle. It would stand to reason that the more mitochondria and oxidative enzymes present in the muscle the greater would be the $\dot{V}O_{2\max}$ of the individual. As an individual trains, his/her $\dot{V}O_{2\max}$ increases, partially due to the increase of mitochondria and oxidative enzymes present in the muscle (expand arteriovenous O_2 difference). Therefore, when an elite athlete with a high mitochondria concentration is compared with a normal individual with a normal mitochondria concentration it is easy to assume that the reason for the higher $\dot{V}O_{2\max}$ of the elite individual is due to higher levels of mitochondria. This would lend support

to the argument that mitochondria number and oxidative enzyme concentration are related to maximal oxygen uptake. The argument against this theory is found in a paper written by Costill et al. (11). They found that muscle mitochondria number can differ greatly among elite athletes, and yet their $\dot{V}O_{2\max}$ values do not differ. Also, it has been found that small changes in muscle respiratory capacity are not associated with increases in $\dot{V}O_{2\max}$, and vice versa (30, 37). This latter evidence leads physiologists to believe that the metabolic capacity of the muscle is not responsible in limiting maximal oxygen uptake.

Pulmonary diffusion capacity for oxygen

Just as the circulatory system may limit oxygen transport during heavy exercise, so can the respiratory system. As cardiac output increases the transit time of the blood through the vascular bed of the muscles decreases; this also holds true for the transit time of blood through the pulmonary capillaries. It has been thought that the lungs may not supply enough oxygen to the blood because of the velocity of the blood through the capillaries.

In normal individuals the lungs perform their job perfectly and are not the limiting factor. This is evident due to a high level of O_2 saturation of the blood as it leaves the pulmonary capillary during heavy exercise. In contrast, in an elite athlete the transit time is less because of a greater maximal cardiac output, and the lungs cannot saturate the blood as it passes through the pulmonary capillary. This has been demonstrated in Peter Snell who is a former world record holder in the mile. During a maximal exercise test Snell's oxygen saturation was 80% (9). Demsey (18), and Powers, et al. (52) confirmed this finding that arterial desaturation occurs in elite

athletes. Additional proof was provided in Powers and colleagues' paper in which a hyperoxic gas mixture increased the $\dot{V}O_{2max}$ of elite athletes but had no effect on the $\dot{V}O_{2max}$ of normal individuals (52). Due to these observations it is reasonable to assume that the lungs are not a limiting factor during heavy exercise unless the subject is an elite athlete who can achieve a very high cardiac output.

In conclusion, while all of the above factors interact to determine an individual's $\dot{V}O_{2max}$, it has become clear that in normal individuals the cardiovascular system (maximal cardiac output) is the principal limiting factor. In elite athletes pulmonary perfusion may play a role in limiting maximal oxygen uptake, but it is believed that the major limiting factor is maximal cardiac output.

Effect of Test Protocol on the Measurement of $\dot{V}O_{2max}$

$\dot{V}O_{2max}$ is one of the most commonly measured variables in exercise science laboratories. Although there are a variety of factors that can affect the measurement of $\dot{V}O_{2max}$ this section of the review will concentrate on the effect exercise protocols have on the attainment of maximal oxygen uptake. It is desirable to have a progressive test that can provide a measure of $\dot{V}O_{2max}$ quickly, accurately, and without the necessity for repeated testing (29). In addition, investigators typically choose a protocol they think will elicit a subject's true $\dot{V}O_{2max}$. When choosing a GXT researchers examine several protocol variables: continuous or discontinuous, mode of exercise, testing intensity, and test and stage duration.

Continuous vs. discontinuous

GXT protocols are either continuous or discontinuous. In a continuous testing protocol the workload is increased at specified increments, in sequential order, and with no rest between stages. On the other hand, discontinuous protocols may be completed on the same day or over several days with a rest period between increments.

McConnell found that a continuous protocol was most efficient in terms of testing time and was deemed less difficult for the subject (43). Taylor et al. (1955) performed one of the better known studies on maximal oxygen uptake using a discontinuous protocol. In this study subjects ran at a constant speed (7 mph) while the grade was increased 2.5% each stage (day). The subjects returned on subsequent days until the 2.5% grade increase elicited a plateau in oxygen uptake (70). Some authors feel that a discontinuous protocol such as this one may achieve higher values of $\dot{V}O_2$ than a continuous protocol (23, 26), however, Duncan et al. found that the $\dot{V}O_{2max}$ values and achievement of $\dot{V}O_{2max}$ criteria were independent of the testing protocol (continuous vs. discontinuous). They concluded that even though most of the objective criteria for attaining $\dot{V}O_{2max}$ were developed using discontinuous protocols, they can also be applied to continuous test protocols (20). So for the sake of time and due to its more simplistic nature a continuous protocol is the most practical testing procedure.

Mode of exercise: Cycle vs. Treadmill

When choosing a mode of exercise it is important to make note of the population being studied. If the subjects are obese, elderly, or suffer from orthopedic

limitations a non-weight-bearing test using a cycle ergometer may be the best option. Also, an important consideration is the training habits of the subjects. If the subjects are highly trained cyclists, they will perform better using a cycle test; if they are elite runners, a treadmill test should be used (66).

It has been established in normal individuals that the measured maximal oxygen uptake on a cycle test is lower than when a test is performed on a treadmill (8, 26, 31). This is due to the size of the muscle mass being used for each of the exercises. Running requires more muscle mass than cycling; therefore, running will provide the highest oxygen uptake values. Shephard states that, in general, uphill treadmill running gives a purer indication of overall physiological endowment, in normal individuals, but a sport-specific test is more useful in predicting the outcome of a particular type of competition (66). Unless elite cyclists are being tested the best mode of exercise that will produce the highest $\dot{V}O_{2\max}$ is a running GXT. Due to the fact that treadmill tests produce higher oxygen uptake values the remainder of this review will focus on graded exercise tests utilizing a treadmill.

Treadmill GXT's

Several factors need to be taken into account when an investigator chooses a treadmill protocol. These factors include treadmill grade and speed, and increments of the test.

Grade vs. speed

The grade and the speed of the treadmill during a GXT are the two most important considerations. In reference to grade, the investigator must first determine whether he or she wants the subject to run uphill or on a flat surface. If the

investigator is interested in obtaining the highest $\dot{V}O_2$ then he or she will want the subject to run uphill (66). The reason for this is the same reason why the cycle ergometer gives lower $\dot{V}O_2$ values. When an individual is running uphill more muscle mass is being used than when running on a flat surface. Finally, the investigator must also determine the percent grade change to use at each interval.

Speed is selected according to the runner's level of training, with approximate training pace being more appropriate for well-trained runners (10, 43). As discussed earlier, flat surface running uses less muscle mass than uphill running, and therefore, produces lower $\dot{V}O_{2max}$ values. Also, if the speed of the treadmill is increased concurrently with the grade the runner may have a difficult time adapting to this "double" increase in intensity. Therefore, several investigators feel that the best treadmill GXT protocol is one that keeps the speed constant while the grade is increased in fixed increments (27, 50, 62, 70).

The grade and speed of the treadmill dictate the intensity of the exercise test and are therefore the integral variables determining how long a test will last. What needs to be determined is the rate of increase in intensity during the test. It has already been established that raising the grade with the speed held constant is the best way to perform a GXT. If the attainment of $\dot{V}O_{2max}$, as opposed to steady state at each stage, is the desired outcome then protocols with shorter exercise increments are more efficient with regard to testing time and may be perceived as being more favorable by the subject (43). Clarke and McConnell compared protocols with 1 versus 2-minute increments for assessment of maximal oxygen uptake in well trained

runners and found no significant difference between protocols (10). Similarly, Fairshter and associates found that short duration protocols using 15 second increments were not significantly different than 1 minute increments when $\dot{V}O_{2max}$ was compared (22). Therefore, many investigators feel the use of 1 minute increment (stages) for a GXT is the best choice (43).

Also, when stage increment is considered, many investigators examine the increase in oxygen uptake per stage. The greater the increase in $\dot{V}O_2$ per stage the more rapidly a subject will become exhausted. For example, studies performed by Weiner and Lourie (72) and Fardy and Hellerstein (23) recommend the test protocol approximate a 5-10% increase of predicted maximal oxygen uptake every two minutes.

Test duration

When grade, speed and stage increment are combined these three factors determine the length of the exercise test. Investigators disagree about what the optimum length of an exercise test should be in order to attain a true $\dot{V}O_{2max}$. Buchfuhrer provided evidence that long duration tests would produce lower max values due to muscle fatigue, greater dehydration, and increased body temperature (8). Therefore, he determined that the subject should be brought to the limit of tolerance within ten minutes.

In Froelicher's experiment involving the comparison of the Balke, Bruce, and Taylor protocols he found that the test with the shortest time to exhaustion (Taylor) produced the highest average maximal oxygen uptake. The other two protocols, the

Balke and the Bruce, showed no difference in average $\dot{V}O_{2\max}$ values (26). Even though these protocols use different workloads and the Balke is a walking protocol it does support the notion that shorter protocols will elicit higher maximal oxygen uptake values. Furthermore, Froelicher supports Buchfuhrer's statement that longer protocols will elicit lower $\dot{V}O_{2\max}$ values.

In evaluating the length of a GXT Åstrand and Saltin (5) found that tests of shorter duration were ideal (2-6 minutes). Additionally they found no difference in $\dot{V}O_{2\max}$ values when comparing a 2-minute GXT to a 6-minute GXT as long as a proper steady state warm-up was performed previously. They state the selection of the protocol was entirely up to the preference of the subject, whether he or she would rather run at a high workload for only two minutes, or run at a somewhat "lower" workload for 6 minutes.

From this evidence we gather that most authors believe that as long as the testing protocol is below approximately 10 minutes in length, the $\dot{V}O_{2\max}$ of the subject can be accurately attained. Also, evidence shows that different durations under this 10-minute "cut-off" will not result in significantly different maximal oxygen uptake values.

Other factors to consider

There are several other factors that can affect the measurement of $\dot{V}O_{2\max}$. Many investigators feel that a proper warm-up is necessary to achieve the highest oxygen uptake value (66, 70). In addition, the motivation of the subject performing the test is very important. It is the investigator's duty to encourage the subject to

exercise to exhaustion. Several papers state that every subject was *encouraged* to complete an entire stage (20, 42). Properly motivated subjects are more likely to work maximally to true exhaustion and will achieve the highest values of $\dot{V}O_2$. An additional factor to consider is that the subject should be fasted before the exercise test. Froelicher recommends that subjects not eat 4 hours prior to the exercise test (26). The reason for this is that blood flow redistribution will occur due to the digestive processes, and the working muscles might receive less blood flow. Another factor is the impact previous physical activity may have on the achievement of $\dot{V}O_{2max}$. Stamford says that the subject should avoid vigorous physical activity on the day before testing. However his data indicate that while previous physical activity will have an impact on time to exhaustion, results show that $\dot{V}O_{2max}$ values are not different (68).

One last factor that can have an impact on maximal oxygen uptake is the way in which the expired gases are sampled. Sampling has to do with the time frame in which the gas samples are collected. Whether they are collected in the last thirty seconds of the stage or by breath by breath analysis the sampling time can influence the data. Myers states that sampling can have a profound effect on the interpretation of gas exchange data during an incremental exercise test (47).

Summary

Shephard and McConnell have each extensively researched graded exercise testing. In 1984 Shephard made a list of common points that should be considered

while performing a GXT that reiterates some of the points already discussed in this review (66).

1. Test endpoint is dependent on the motivation of the individual subject, or the person supervising the test.
2. It is necessary for the subject to continue exercising to total exhaustion.

Similarly, McConnell developed a set of guidelines for protocol selection that should always be followed if the investigator wishes to observe the most accurate $\dot{V}O_{2\max}$ for runners (43).

1. A comfortable treadmill speed should be selected for the subject
2. The speed of the treadmill should be held constant with increments in grade
3. Total testing time should be between 7 and 10 minutes
4. Use continuous tests since their maximal oxygen uptake values are equal to discontinuous, and test time will be shorter
5. Use short stage increments since this may be more desirable to the subject
6. Test should be preceded by a warm-up of 5-10 minutes at $\geq 50\% \dot{V}O_{2\max}$

Criteria for Having Achieved $\dot{V}O_{2\max}$

During a graded exercise test, it is of utmost importance that the subject gives a maximal effort and exercise to true exhaustion. If the subject quits the test before he or she is truly exhausted the oxygen uptake values observed could be lower than the true $\dot{V}O_{2\max}$. On the other hand, if there is a way to tell that the subject did indeed exercise maximally, then his or her $\dot{V}O_{2\max}$ value can be taken as a true value of their

cardiovascular fitness. There are several signs an investigator looks for to determine whether the individual has exercised maximally.

Plateau in oxygen uptake

The first of these signs of maximal effort is a plateau in oxygen uptake in the last stages of the test. In all subjects it has been shown that as workload increases so does $\dot{V}O_2$; however, in some subjects there is an upper limit to which further increases in workload are no longer accompanied by increases in oxygen uptake, thus a plateau is seen.

“The plateau is theoretically exact, in practice it is much less so” (14). The problem with using a plateau in oxygen uptake as an indicator of maximal effort is that not all subjects elicit a plateau even if they exercise maximally. It has been suggested that the inability to elicit a plateau can be due to lack of motivation or a low anaerobic capacity (16, 59). The occurrence of a plateau depends on the definition, population, and protocol (14, 47, 70). Additionally, the attainment of a plateau depends on the increment between stages (8, 21, 26, 46), the muscle mass involved (71), and the training status of the individual (7, 51).

There have been several different definitions developed to define what a plateau is. In other words, the attainment of a plateau depends on the degree of increase in $\dot{V}O_2$ from stage to stage. For example, a plateau exists when $\dot{V}O_2$ values (the last three stages at least) do not differ by more than 3% (49). Taylor, using the discontinuous protocol discussed earlier, defined a plateau by the use of 2.5% changes in treadmill grade not accompanied by less than half of the expected increase in oxygen uptake ($\leq 2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) (70). Several other investigators have used this

criterion without reference to their protocol (16, 56, 59, 60, 67, 74). The problem is that this definition is protocol specific. Other protocols will not have the same expected increase in $\dot{V}O_2$ per stage. Therefore, this $\leq 2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ standard should not be assumed to hold true with other protocols (i.e. Balke and Bruce) (20, 33).

Because the plateau definition can be protocol specific several authors adapted a definition for a plateau based on their protocol. For example, to define a plateau in their experiments, Mitchell used a $\leq 54 \text{ ml/min}$ increase in oxygen uptake (45), while Stamford used an increase $\leq 112 \text{ ml/min}$ between successive stages (68), and Cumming defined a plateau using a cycle ergometer, as the failure of two successive stages to increase $\dot{V}O_2$ over 50 ml/min (15).

Myers and Freedson have provided more general definitions of a plateau. These definitions are important because they are not protocol specific, and can therefore be used for any GXT. Myers observed the slope of oxygen uptake as it changed with increasing workloads. If the slope of the line is not significantly different from zero this suggests that $\dot{V}O_2$ is not increasing concomitantly with external work and therefore a plateau was observed (47). Freedson feels that the plateau criterion used to define $\dot{V}O_{2\text{max}}$ should be based on either individual or average responses to any protocol employed in order to maximize the proportion of the subjects satisfying this criterion (25). She described 3 new criteria to be used: (a) $\Delta \dot{V}O_2 \leq \text{Average } \Delta \dot{V}O_2$ among submaximal stages for each individual; (b) $\Delta \dot{V}O_2 \leq$ the lowest change among four submaximal stages for each individual; and (c) $\Delta \dot{V}O_2 \leq$

3.7 ml·kg⁻¹·min⁻¹ or the average change among 4 submaximal stages for an entire group (25). Upon completion of the test she would look at the average increase in oxygen uptake for the individual. She would then observe whether the subject showed an increase over the last two to three stages less than the average of the previous stages. If the change over the last two stages was equal to or less than the average change then this individual demonstrated a plateau.

As mentioned earlier, a problem with using a plateau in oxygen consumption as a criterion for $\dot{V}O_{2max}$ is that, no matter what definition is used, not all subjects will elicit a plateau. McConnell found that maximal oxygen uptake values were not different between the same subjects when a plateau was obtained and when it was not (43). Given one preliminary attempt most adult volunteers can reach a classical plateau of oxygen consumption (66).

The following are many examples of experiments in which not all subjects elicited a plateau. In Taylor's aforementioned study, only seven of 115 subjects failed to reach his criterion value of ≤ 2.1 ml·kg⁻¹·min⁻¹ increase in oxygen uptake between the last two levels established for the plateau on oxygen uptake (70). Similarly, although it is surprising based on his definition (≤ 54 ml/min), Mitchell found that 75% of his subjects reached a plateau on the treadmill (45). In a study conducted in 1984 using different treadmill protocols Davies et al. found 74% of runners reached a plateau; a plateau was not obtained in only 6% of tests (17). In a study performed by Froelicher in which he compared three traditionally used GXT's (Taylor, Bruce and Balke) a plateau was observed in 33% of subjects for the Taylor protocol, 17% in the

Balke protocol, and 7% for the Bruce protocol (26). In another study, Katch and associates, observed a plateau in 61% of their subjects (35). The Åstrands, in their study on older men observed a plateau in all 9 subjects as the workload increased (2).

Since a plateau in oxygen uptake is not always observed, it is not a “prerequisite for defining $\dot{V}O_{2\max}$ and is of limited use as the primary objective criterion for evaluating the quality of the graded exercise test” (20). If a plateau in $\dot{V}O_2$ does not occur in a subject, possible options are to repeat the test or attempt an assessment of the supposed maximal effort based on other physiological factors (66). It is these physiological factors that are of primary importance for the remainder of this review.

Investigators tried to identify these other physiological variables that would indicate that the subject was working maximally when the highest oxygen uptake was measured. “Therefore, the achievement of secondary objective criteria, specifically, the magnitude of the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ and post-exercise lactate in combination, increases the likelihood that the highest $\dot{V}O_2$ value achieved is $\dot{V}O_{2\max}$ ” (20). In addition, as an indicator of maximal effort, the maximal heart rate observed during the GXT is frequently used.

Heart rate

Maximal heart rate is the most practical indicator that work intensity is reaching a maximum (14). In an early study Maritz used an increase in heart rate to estimate maximal oxygen uptake values as an indicator of maximal work (41). Since that time, the equation $220 - \text{age}$ ($SD = \pm 11$) has been found to be an unreliable measure

of an individual's maximum heart rate (39) due to individual variability. Still, investigators use heart rate as an indicator of effort because it is non-invasive and easily observed.

As with the plateau phenomenon, there are several opinions present in the literature relating to heart rate and maximum effort. For example, some investigators believe if a subject reaches a heart rate ± 15 beats (25) or ± 10 beats (66) from the subject's age predicted maximum heart rate, then he or she has shown a maximal effort. Since there is so much variation, the heart rate observed during the GXT is an extremely poor indicator of effort and should not be used a criterion for having achieved maximal oxygen uptake.

Post-exercise lactate

A criterion that is more indicative of maximal exercise than heart rate is the subject's post-exercise blood lactate concentration. The energy need at high working intensities increases more steeply than the oxygen uptake and an increasing amount of the work must be paid for by anaerobic processes (3). As anaerobic metabolism increases, NADH production exceeds the cell's capacity for shuttling electrons down the respiratory chain. This build up of hydrogen ions reacts with pyruvate causing lactate to accumulate (36). The high lactic acid concentration proves that the anaerobic processes played an important role in delivering energy, and thus the effort was maximal (2, 20, 62). The blood lactate criterion is helpful in evaluating whether or not the short-term exercise has been maximal (the subject exercised to exhaustion) (2, 5, 62). In his study on children Åstrand was the first to establish a post-exercise lactate criterion (8 mM) for maximal effort (3). Since this study many other

investigators adopted this criterion (14, 16, 20). The problem with this is that some investigators may use a lactate criterion in hindsight. After the study is completed, they then determine what post-exercise lactate range their subjects fit best, and then use that criterion or suggest another. Irma Åstrand and associates used a lactate level above 7.3 mM as an indicator of maximal effort in tests performed on elderly men (2). Dobeln and colleagues used the lowest value of 5.5 mM as their criterion of maximal effort (19). Cumming states that these values may be too low to assume that near max $\dot{V}O_2$ values are recorded (14). Shephard was less specific and used lactate levels "approaching" 10 mM to determine whether his subjects exercised maximally (67).

There seems to be great variation in the literature as to what concentration of lactate is truly reflective of maximal effort. This discrepancy can possibly be due to the inter-individuality of lactate concentration related to age and training status. Nevertheless, the standard commonly used today is a blood lactate level greater than 8 mM, as established by Åstrand.

RER

The fourth criterion used to establish maximum effort during a GXT is the magnitude of the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$, the respiratory exchange ratio (RER). The RER is an indirect estimate of the change in blood lactate concentration, since the buffering of the lactic acid generates CO_2 (34). "It seems logical that if the lactate criterion were achieved then the RER criterion would also be achieved" (20), however this is not always the case. Again, as with the previous three criteria there are several RER standards used by different investigators to establish maximal effort. As Åstrand did with the lactate standard, Issekutz was the first to establish a standard for

RER using a discontinuous test. His commonly utilized standard of an RER greater than 1.15 indicates that the subject exercised maximally (34). Duncan actually tested whether Issekutz' standard was applicable to continuous tests and found that it was (20). There have been several other proposed criteria for RER. For example, Davies, et al. used an $\text{RER} \geq 1.0$ (17) and McMiken and Daniels used an $\text{RER} \geq 1.10$ (44) to suggest that the subject exercised maximally. The rationale for these latter standards is not clearly established in their text. Again, as with the lactate and heart rate criteria there are several different RER standards utilized by different investigators.

It is not clear in which manner to use these secondary criteria when a plateau is not observed. It is necessary to establish a series of standards that once achieved, will increase the likelihood that a true $\dot{V}\text{O}_{2\text{max}}$ has been obtained (20). These standards could possibly depend on the tested population. For example, the lactate standard may be lower for children ($\approx 6\text{-}7$ mM) than adults ($\approx 8\text{-}10$ mM). Also, researchers are not sure how to use secondary criteria, alone or in combination (66). Cumming suggested that before accepting values as maximal it is preferable that two of the four proposed criteria be exceeded (14). Cumming feels strongly that if the subject does not attain a plateau in oxygen uptake then available secondary criteria are obviously not entirely satisfactory and $\dot{V}\text{O}_2$ values should be considered as near maximum values (14). It is evident that a standard needs to be developed across populations and protocols (33).

Conclusion

In summary, even though $\dot{V}O_{2\max}$ has been the most commonly measured variable in exercise physiology laboratories its measurement and interpretation are inconsistent. There are so many factors that influence the measurement and interpretation of a GXT. In considering a GXT protocol there are several options that lie before the investigator. He or she can use different modes of exercise, use different lengths of test duration, and use different increments of exercise intensity.

It has been found that the protocol used in a GXT can have a profound effect on the attainment of $\dot{V}O_{2\max}$, and for that matter a plateau in $\dot{V}O_2$. If the subject elicits a plateau it is commonly acknowledged that they did in fact "max out." The only problem is that there are many different interpretations of what a plateau in $\dot{V}O_2$ actually is (i.e. $\leq 2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, or $\leq 54 \text{ ml/min}$). Likewise, there is disagreement concerning which standards to use with the other three physiological factors (heart rate, post-exercise lactate, and RER), thus making the analysis of a $\dot{V}O_{2\max}$ test much more difficult than it should be.

Chapter III

Methods

Ten healthy male subjects under the age of 45 were recruited from the Knoxville, Tennessee community to participate in the study. To qualify, the individuals had to have been participating in running workouts at least four times per week at a moderate-to-vigorous intensity for at least thirty minutes per workout. In addition, all subjects must not have answered "yes" to any question on the Physical Activity Readiness Questionnaire (PAR-Q: see Appendix A).

Each subject completed four exercise tests in the UTK Applied Physiology Laboratory on four different days. Each test session lasted approximately one hour. The subjects were asked not to eat for three to four hours nor have exercised for 12 hours prior to each lab visit. The subjects were encouraged to drink plenty of fluids, especially water, on the day of the testing session.

Baseline Data

On the first visit to the lab the subjects were asked to read and sign an informed consent form (see Appendix B) which was approved by the University of Tennessee's Institutional Review Board. Additionally, the subjects were asked to complete a brief health history questionnaire (Appendix C), and then the PAR-Q. During this visit the subjects were shown the equipment and procedures utilized for this project, and age, height, and weight were obtained. During the familiarization process each subject had an opportunity to run on a Model Q55XT treadmill (Quinton Instruments, Seattle, WA) at a variety of grades and speeds. Also, each subject was

fitted with a Polar Vantage XL heart rate monitor (Polar CIC Inc., Port Washington NY), nose clip and mouthpiece to be used in the collection of data. All subjects were encouraged to ask questions related to any phase of the study they believed was unclear.

Test for Maximum Heart Rate

After the subject felt comfortable running on the treadmill he performed a formal "warm-up" and completed a graded exercise test to exhaustion. In each of the four protocols the treadmill speed was calibrated with the use of a handheld DT-107 tachometer (Shimpo Instruments, Itasca, IL). The warm-up consisted of running for ten minutes at a speed that elicited a heart rate of approximately 150 beats per minute (as monitored by the heart watch). This was followed by a five-minute rest period, and then the graded exercise test began. The treadmill speed was held constant at 7 miles per hour, while the grade was increased 1% each minute. The test was terminated when the subject reached volitional exhaustion. At the point of exhaustion, the subject's maximal heart rate was noted from the heart rate monitor and used as the intensity criterion for the remaining exercise tests.

Tests for $\dot{V}O_{2max}$

The second, third and fourth test sessions assessed the subject's maximal oxygen uptake. These three GXT's were performed within a two-week time span for each subject. The same GXT procedures used for the first lab session were used for these tests except the test stage durations were 30 seconds, 60 seconds or 90 seconds, and the warm-ups were different. The test order was randomly assigned, and on each of these visits the subject's weight was noted. During the tests the subject wore the

heart rate monitor used previously, a nose clip, and a mouthpiece connected to a Hans Rudolph (Kansas City, MO) two-way, non-rebreathing valve (2700 series, Large). Inspired gas volumes were measured using a Rayfield ventilation meter (Rayfield Equipment Ltd., Waitsfield, VT). The expired gas was passed through a mixing chamber and analyzed by an Applied Electrochemistry (Applied Electrochemistry Inc., Sunnyvale, CA) S-3A O₂ analyzer and a Beckman LB-2 Medical Gas Analyzer (Advanced Technology Operations, Fullerton, CA) CO₂ analyzer. The analyzers were calibrated prior to the initiation of each test with a three-point calibration system using nitrogen and two gas mixtures of known oxygen and carbon dioxide concentration. The calibration gases were verified prior to the study using the micro-Scholander technique (64). This ensured that the gas analyzers were reasonably linear. Gas exchange was measured and calculated using a Rayfield Automated System (Rayfield Equipment Ltd., Waitsfield, VT) utilizing a 20-second delay with a hard copy provided every 30-seconds.

To warm up, the subject ran on the treadmill at 6 mph and the speed was increased 1/2 mph per minute until the subject reached eighty percent of the maximum heart rate obtained from the first session. After that heart rate was reached the subject continued to run at that speed for two additional minutes; this was followed by a ten-minute rest period. The subject then began running at the speed that elicited 80% of his maximal heart rate (this speed was also used for all of his subsequent tests). The grade of the treadmill was increased 1% at the end of every stage (30s, 60s, or 90s), and the subject exercised to exhaustion. Subjects were verbally encouraged by the

investigators to achieve their highest level in each test. $\dot{V}O_{2\max}$ was chosen as the highest level of oxygen uptake during any 30 second interval measured during the test.

After the termination of each of the graded exercise tests, the subject dismounted the treadmill and lay supine. After two minutes a blood sample was obtained by a finger prick with a sterile lancet. One hundred microliters (approximately 4 drops) of the subject's blood were placed in a storage vessel (containing an anticoagulant, and an antimetabolic agent) until later analysis of lactate using a YSI Model 2300 Stat Plus Glucose and L-Lactate analyzer (YSI Inc., Yellow Springs, OH). All blood samples were analyzed for lactate not more than two hours after the completion of the GXT's. Universal precautions were followed according to OSHA guidelines.

Statistical Analysis

The criteria for $\dot{V}O_{2\max}$ used in this investigation were a plateau in $\dot{V}O_2$ as defined as a change in oxygen uptake over the last 2 stages of less than half the average change of stages 2-5, a post-exercise blood lactate greater than 8.0 mM, and an RER greater than 1.15. One way repeated measures ANOVA was used to recognize differences between protocols for the following variables: $\dot{V}O_{2\max}$, post-exercise lactate, RER, time to exhaustion, and grade achieved at exhaustion. This analysis was followed with an F test on the within subjects effect to test for differences between trials. The number of plateaus achieved for each protocol was tested for significance using a chi-square test.

Chapter IV

Results

This study was designed to evaluate the effect of length of stage duration of a GXT on the occurrence of a plateau in oxygen uptake. A complete list of individual subject data is located in Appendix D. Table 1 shows that the design had the desired effect. The 30-second stage resulted in the shortest test ($p < .001$) and highest grade achieved ($p < .001$) compared to the other two treatments.

The value chosen as maximal oxygen uptake was the highest oxygen uptake achieved in any 30-second gas analysis interval. As Table 1 indicates the highest $\dot{V}O_{2\max}$ value was associated with the shortest stage interval while the lowest $\dot{V}O_{2\max}$ value was associated with the longest interval. However, the repeated measures analysis of variance indicates that the differences among the maximal oxygen uptake values were not significant ($p = .142$).

The post-exercise lactate value followed the same pattern as $\dot{V}O_{2\max}$, with the 30-second stage eliciting the highest values. In this case the latter value was significantly higher than those from the other two protocols ($p < .05$), with no significant difference existing between the 60 and 90-second values ($p > .08$).

The RER value was highest for the 30-second stage protocol ($p < .001$), and like the post-exercise lactate the 60 and 90-second protocols were not significantly different ($p > .09$).

Table 1. Average values for subjects during the three protocols

	$\dot{V}O_{2\max}$	Lactate	RER	Grade	Time
30 Second	57.4 $\pm$ 2.5	10.3 $\pm$.7*	1.21 $\pm$.02 ⁺	10.8 $\pm$.7 [#]	5.9 $\pm$.3 [#]
60 Second	56.2 $\pm$ 2.6	9.4 $\pm$.8	1.15 $\pm$.02	8.4 $\pm$.6	9.4 $\pm$.6
90 Second	54.5 $\pm$ 1.8	8.6 $\pm$.8	1.11 $\pm$.02	7.0 $\pm$.5	12.0 $\pm$.7

Note: Values are expressed as Mean $\pm$ SEM

Values for $\dot{V}O_{2\max}$ are expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$

Values for post-exercise lactate are expressed in mM

Grade and time are expressed in % and minutes respectively

*Denotes a significant difference between 30 second and 60 second, and 30 second and 90 second protocols ($p < .05$)

+Denotes a significant difference between 30 second and 60 second, and 30 second and 90 second protocols ($p < .001$)

#Denotes a significant difference between all protocols ($p < .001$)

Table 2 shows the number of subjects in which a plateau was elicited based on the study criteria (a change in $\dot{V}O_2$ over the last two stages of less than half of the average change in $\dot{V}O_2$ of stages 2-5). There were a total of nineteen plateaus observed out of thirty tests. Seven plateaus were observed during each of the 90-second and 60-second protocols, while five plateaus were achieved during the 30-second protocol. Based on the chi-square test there were no significant differences found between the number of plateaus observed for each protocol ($p > .05$).

Table 2. Number of individuals (out of 10) showing a plateau in oxygen uptake during each protocol achieved during each protocol (30, 60 or 90 seconds)

30 Second	60 Second	90 Second
5	7	7

Chapter V

Discussion

The purpose of this study was to determine whether the length of stage duration of a graded exercise test affects the occurrence of a plateau in oxygen uptake. In the study ten subjects were exercised to exhaustion using three different treadmill protocols. The three protocols differed by the time increments between increases in treadmill grade (30-seconds, 60-seconds, and 90-seconds). It was hypothesized that the shorter duration test would result in more plateaus in oxygen uptake. The variables analyzed were plateau occurrence, $\dot{V}O_{2max}$, RER, post-exercise blood lactate, time to exhaustion, and grade at exhaustion.

The criteria used to determine if a maximal effort was given were:

1. Plateau in oxygen uptake (a change in $\dot{V}O_2$ over the last two stages of less than half of the average change in $\dot{V}O_2$ of stages 2-5).
2. Post-exercise lactate >8 mM
3. RER > 1.15

This study found that for the 30-second protocol, 50% of the subjects achieved a plateau in $\dot{V}O_2$, while 90% achieved the criterion for RER and post-exercise lactate. Seventy percent of the subjects achieved a plateau in the 60-second protocol, while 60% of the subjects achieved the post-exercise lactate criterion, and 70% satisfied the criterion for RER. Lastly, for the 90-second protocol, 70% of the subjects demonstrated a plateau, 50% of the subjects obtained a post-exercise lactate >8 mM, and only 30% satisfied the RER criterion.

Cumming suggested that before accepting values as maximal it is preferable that two of the four proposed criteria be exceeded (14). This study only used three of the originally proposed four maximal effort criteria (RER, post-exercise lactate and a plateau $\dot{V}O_2$). In this investigation four subjects did not achieve at least two out of the three criteria of maximal effort on at least one test. While the remaining six subjects satisfied at least two out of the three criteria for each test protocol. Appendix D shows that Subject #1 never satisfied two out of the three criteria for any test. The reader might wonder if these $\dot{V}O_{2max}$ values should be accepted as this subject's true maximal oxygen uptake, or that they be accepted as near maximal values as proposed by Cumming (14).

We hypothesized that during the shorter stage tests the subject would have anaerobic energy left over at the end of the test to work at increasing workloads without an increase in oxygen uptake. However, as Table 2 indicated, the occurrence of a plateau in $\dot{V}O_2$ did not differ significantly between treatments. Each subject was encouraged to complete a full stage before terminating the test. This made many subjects reluctant to keep working to the next stage for the 60 and 90-second protocol (the last 90-second increment seemed like a lifetime). In contrast, during the 30-second increments the subjects felt they could tolerate another 30 seconds more. This willingness of the subjects to push to an additional stage in the 30-second protocol and not in the 60 and 90-second protocol is another reason why we thought more plateaus would be seen for the 30-second protocol.

However, our hypothesis is rejected due to the fact that the 30-second test elicited fewer plateaus, even though this treatment was not significantly different from the others. Appendix D shows that only one subject (#10) did not elicit a plateau during any of the protocols, while three subjects (#2,8,9) elicited a plateau during every protocol. The remaining six subjects reached a plateau during one or more, but not all of the protocols. It is not known why there is such a discrepancy between subjects, but different levels of training among the subjects could have contributed to this variability. It is apparent from this study that the occurrence of a plateau is independent of stage duration when stages range from 30 to 90 seconds.

In addition to the frequency of plateau occurrence, the maximal oxygen uptake each subject achieved during the tests was analyzed. Figure 1 clearly demonstrates the different rates of oxygen uptake, while also showing the differences in mean $\dot{V}O_{2\max}$

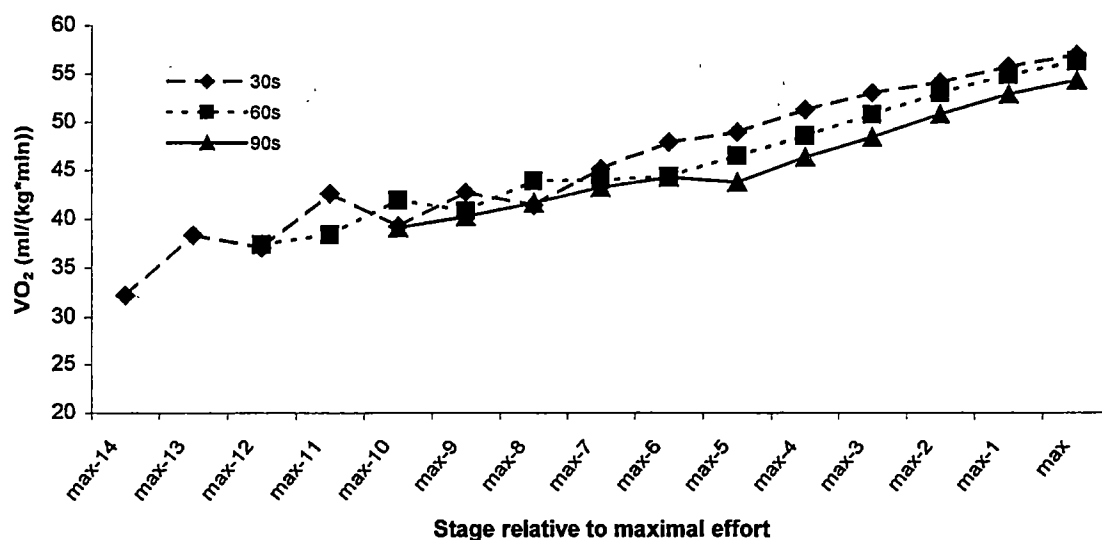


Figure 1. Average $\dot{V}O_2$ chosen as the highest per stage for all subjects during three graded maximal exercise tests

values for the three different protocols. As stated previously, maximal oxygen uptake was chosen as the highest level of oxygen uptake achieved in any thirty-second gas analysis interval.

Figure 2 better represents the different rates of oxygen uptake for the three different protocols. The 30-second protocol clearly increased oxygen uptake at a much more rapid rate than the 60 and 90-second protocols. Figure 2 also illustrates the differences in time to exhaustion for each protocol. There also seemed to be a threshold for each of the protocols at which $\dot{V}O_2$ begins to increase much more rapidly than the previous stages. Each protocol shows approximately the same rate of oxygen uptake for the first few stages, then they begin to "branch" upward from each other. The 30-second stage "branches" off first, at three and a half minutes, while the 60-second protocol rises sharply at the eight-minute mark, and the 90-second protocol rises sharply at nine minutes.

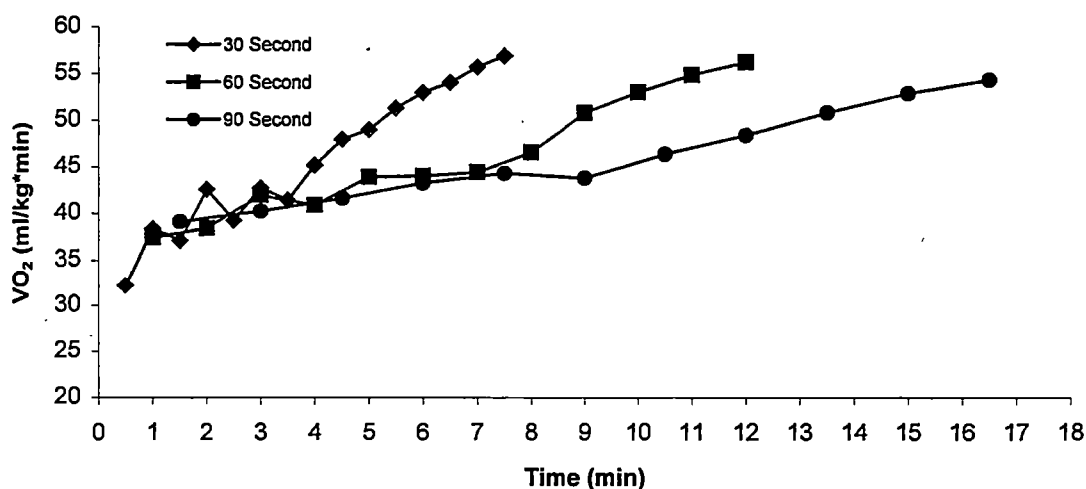


Figure 2. Average oxygen uptake response to three protocols over time

Figure 3 represents the same mean $\dot{V}O_2$ data as Figures 1 and 2 except in this figure the $\dot{V}O_2$ response to a change in treadmill grade is illustrated. This figure shows that grade at exhaustion is inversely proportional to length of stage.

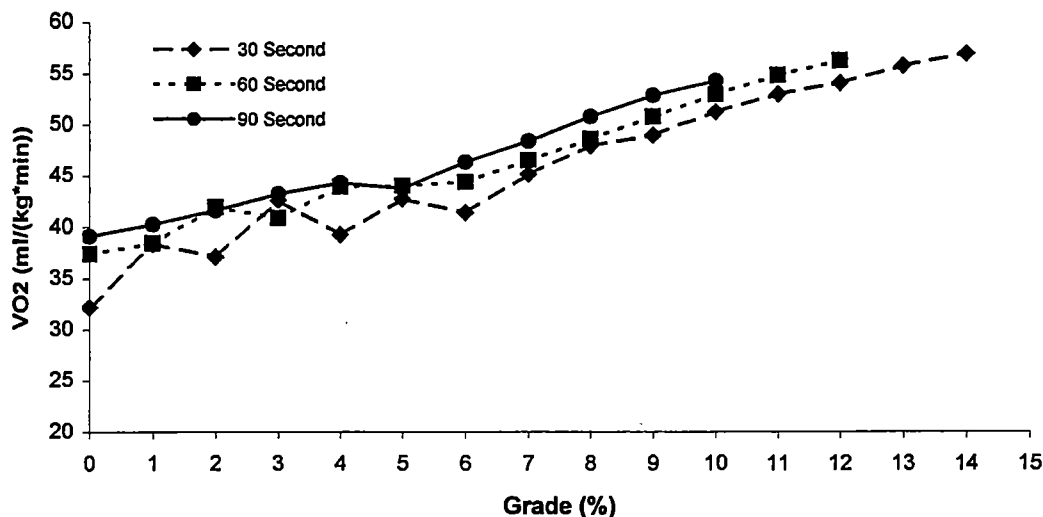


Figure 3. Average oxygen uptake response to three protocols with respect to grade

There was some concern whether this method was the best way to interpret the gas analysis data. Two additional methods of interpretation were discussed. One method used an average of the oxygen uptake values for each stage, with the highest value chosen as the subject's maximal oxygen uptake. If this method were used then the 30-second $\dot{V}O_{2max}$ values would be the same as the other method, but the $\dot{V}O_{2max}$ for the 60-second protocol would be an average of two thirty-second gas analysis intervals, while the $\dot{V}O_{2max}$ for the 90-second protocol would be an average of three thirty-second gas analysis intervals. Another method of interpreting the gas analysis data is to use the oxygen uptake value of the last thirty seconds of each stage, with the highest value taken as the subject's maximal oxygen uptake. Once again the 30-

second values would obviously remain the same, but the 60 and 90-second values might be different.

In order to compare these three different methods of interpreting $\dot{V}O_{2\max}$, a statistical analysis was performed using all three methods. None of the analyses produced results in which the protocols were significantly different from each other. This is evident by observing the means of the three different approaches (Table 3).

Table 3. Mean $\dot{V}O_{2\max}$ values of three different interpretations of the same $\dot{V}O_2$ data for three different protocols

	30-second	60-second	90-second
Highest 30 sec.	57.4 $\pm$ 2.5	56.2 $\pm$ 2.6	54.5 $\pm$ 1.8
Last 30 sec.	57.4 $\pm$ 2.5	55.7 $\pm$ 2.6	53.1 $\pm$ 1.7
Average	57.4 $\pm$ 2.5	55.6 $\pm$ 2.6	53.3 $\pm$ 1.7

Note: Values are expressed as Mean $\pm$ SEM

Values for $\dot{V}O_{2\max}$ are expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$

The lack of significance in $\dot{V}O_{2\max}$ for the method of analysis used in this study (the highest 30-second value observed) may come as a surprise to the reader when observing Table 3. This table shows almost a 3 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ difference between the average maximal oxygen uptake of the 30-second protocol and the 90-second protocol. Appendix D clearly shows the variability of $\dot{V}O_{2\max}$ values of the subjects and protocols. For example, Subject #10's $\dot{V}O_{2\max}$ was $\approx 8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ greater in the 30-second protocol than the 90-second protocol, while Subject #2 demonstrated

the opposite trend. This variability, as explained in Chapter II, is probably due to the day to day variability of the individual when measuring $\dot{V}O_{2max}$. It is commonly found in the literature that a 4-6% difference in maximal oxygen uptake will occur when measuring the same individual on different days with the same protocol (6, 16, 27, 35, 70, 74). The present study found the average individual day to day variability to be 5.4% while measuring each individual using different protocols.

Another possible reason for the variability of values may be due to the potential inaccuracies of the automated system when performing a 30-second measurement. Since there is a twenty-second delay between the expiration of the breath and its subsequent analysis, problems can stem from mismatching the gas fractions to the volume of gas expired. Additional technological problems could be due to missing a breath during one thirty second cycle, and adding it to the next thirty-second cycle. Together these problems can cause inconsistencies of $\dot{V}O_2$ values from one thirty second stage to another.

Investigators state that the duration of a GXT should be below ten minutes (8) to achieve optimal results while Åstrand and Saltin thought that a max test should be between 2 and 6 minutes (5). Even though it was not significant, the shortest GXT produced the highest average $\dot{V}O_{2max}$ compared to the other tests. Appendix D shows that the duration of the 30-second protocol ranged from 4.5 to 7.5 minutes.

The post-exercise lactate response to the treatments was what had been expected, with the 30-second protocol eliciting significantly higher values than the other treatments ($p < .05$). This shows the emphasis shorter duration exercise places

on anaerobic metabolism. Only one subject (#4) had a lower post-exercise lactate after the 30-second protocol; all other subjects had the highest post-exercise lactate level upon the completion of the 30-second protocol. Also, lower post-exercise lactate levels for the longer protocols could be attributed to the subject's unwillingness to proceed to the next stage. Additionally, higher RER values were found during the 30-second protocol when compared with the other two protocols ($p < .05$). This again shows an increased reliance of anaerobiosis during the shorter test. What is curious is that some subjects, especially Subject #3, achieved the RER criteria (>1.15) for maximal effort for two of the protocols but did not achieve the post-exercise lactate criteria (>8 mM) after two of the tests. Duncan states that if the RER criteria for maximal effort is achieved then the lactate criteria will also be achieved, and vice versa (20). This was not the case in this study.

As a side note, even though maximal heart rate was used strictly as a means of selecting the speed of the treadmill for each individual, the maximal heart responses to the three treatment protocols produced an interesting result. Figure 2 shows that the mean heart rate tended to be higher during the test to measure maximal heart rate (the first protocol performed in which no equipment was used except the heart rate monitor) even though the mean was not significantly different from the other three protocols.

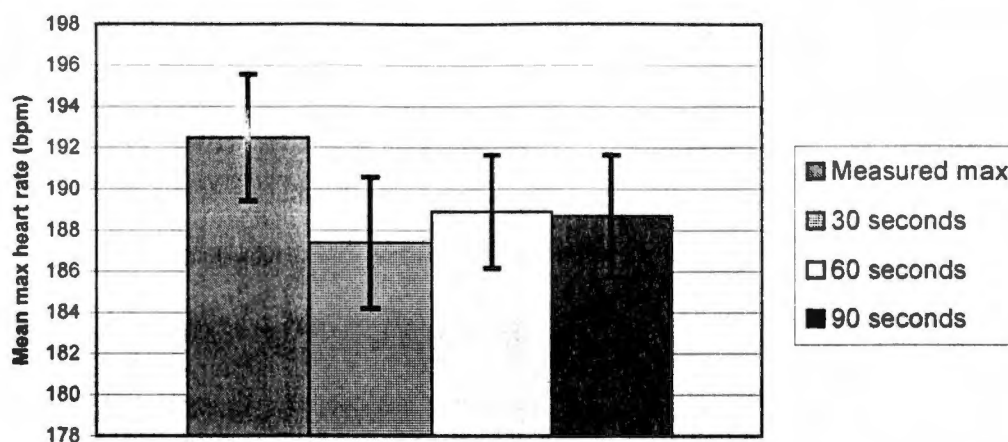


Figure 4. Mean maximal heart rates for all subjects for each protocol performed

Conclusion

In conclusion, this investigation found no significant difference between protocols (30, 60, and 90-second stages) when number of plateaus achieved and maximal oxygen uptake values are considered. However, the 30-second protocol produced significantly higher RER and post-exercise lactate values than the 60 and 90-second protocols. There seems to be great individual variation when these four factors are examined. Some subjects appeared to achieve higher values on one protocol than another. This interindividual variability makes it difficult to draw any firm conclusions regarding the best protocol to use to achieve a plateau.

Recommendations for Further Study

This study found that test protocol did not affect the occurrence of a plateau in oxygen uptake in a group of runners. It would be interesting to test a group of sedentary individuals using the same protocol to see if they elicit the same results. Additionally, more research needs to concentrate on the relationship between

achievement of RER criterion and the achievement of post-exercise lactate criterion, since this investigation found these physiological markers of maximal effort are not always satisfied concomitantly. It would also be interesting to observe the rate of accumulation of lactate for the three different protocols by the use of several blood samples throughout the GXT's. Also, the variability of the results could be due to the automated system based on the 20-second delay and the 30-second printouts. A possible remedy for this would be to perform this study using Douglas Bags, or an automated system with a much shorter delay.

LIST OF REFERENCES

List of References

1. Armstrong, N., J. Welsman, and R. Winsley. Is peak VO_2 a maximal index of children's aerobic fitness? *Internat. J. Sports Med.* 17(5): 356-359, 1996.
2. Åstrand, I., P.-O. Åstrand, and K. Rodahl. Maximal heart rate during work in older men. *J. Appl. Physiol.* 14: 562-566, 1959.
3. Åstrand, P.-O. *Experimental studies of physical working capacity in relation to sex and age*. Copenhagen: Ejnar Munksgaard, 1952.
4. Åstrand, P.-O. and B. Saltin. Maximal oxygen uptake and heart rate in various types of muscular activity. *J. Appl. Physiol.* 16: 977-981, 1961.
5. Åstrand, P.-O. and B. Saltin. Oxygen uptake during the first minutes of heavy muscular exercise. *J. Appl. Physiol.* 16: 971-976, 1961.
6. Boileau, R.A., A. Bonan, V.H. Heyward, and B.H. Massey. Maximal aerobic capacity on a treadmill and the bicycle ergometer of boys 11-14 years of age. *Journal of Sports Medicine and Physical Fitness.* 17: 153-172, 1977.
7. Boutcher, S.H., R.L. Seip, R.K. Hetzler, E.F. Pierce, D. Snead, and A. Weltman. The effects of specificity of training on rating of perceived exertion at the lactate threshold. *Eur. J. Appl. Physiol.* 59: 365-369, 1989.
8. Buchfuhrer, M.J., J.E. Hansen, T.E. Robinson, D.Y. Sue, K. Wasserman, and B.J. Whipp. Optimizing the exercise protocol for cardiopulmonary assessment. *J. Appl. Physiol.* 55(5): 1559-1564, 1983.
9. Carter, J.E.L., F.W. Kasch, J.L. Boyer, W.H. Phillips, W.D. Ross, and A. Sucec. Structural and functional assessments on a champion runner-----Peter Snell. *Research Quarterly.* 38(3): 355-365, 1965.
10. Clark, B.A. and T.R. McConnell. Comparison of treadmill testing protocols to assess $\text{VO}_{2\text{max}}$ in well trained runners. *Abstract: Med. Sci. Sports and Exerc.* 18(Suppl. 176): S36, 1986.
11. Costill, D.L., W.J. Fink, and M.L. Pollock. Muscle fiber composition and enzyme activities of elite distance runners. *Med. Sci. Sports.* 8: 96-100, 1976.
12. Costill, D.L., H. Thomason, and E. Roberts. Fractional utilization of the aerobic capacity during distance running. *Med. Sci. Sports and Exerc.* 5: 248-252, 1973.

13. Cotes, J.E. and R.F. Woolmer. A comparison between twenty-seven laboratories of the results of analysis of an expired gas sample. *J. Physiol.* 163: 36-37, 1962.
14. Cumming, G.R. and L.M. Borysyk. Criteria for maximum oxygen uptake in men over 40 in a population survey. *Med. Sci. Sports.* 4: 18-20, 1972.
15. Cumming, G.R. and W. Friesen. Bicycle ergometer measurement of maximal oxygen uptake in children. *Can. J. Physiol. and Pharm.* 45: 937-946, 1967.
16. Cunningham, D.A., B.M.V. Waterschoot, D.H. Paterson, M. Lefcoe, and S.P. Sangal. Reliability and reproducibility of maximal oxygen uptake measurement in children. *Med. Sci. Sports.* 9: 104-108, 1977.
17. Davies, B., A. Dagget, P. Jakeman, and J. Mulhall. Maximum oxygen uptake utilizing different treadmill protocols. *Brit. J. Sports Med.* 18: 74-79, 1984.
18. Demsey, J.A. Is the lung built for exercise? *Med. Sci. Sports Exerc.* 18: 143-155, 1986.
19. Dobeln, W.V., I. Åstrand, and A. Bergstrom. An analysis of age and other factors related to maximal oxygen uptake. *J. Appl. Physiol.* 22: 934-938, 1967.
20. Duncan, G.E., E.T. Howley, and B.N. Johnson. Applicability of $\text{VO}_{2\text{max}}$ criteria: discontinuous versus continuous protocols. *Med. Sci. Sports Exerc.* 29(2): 273-278, 1997.
21. Fairshter, R.D., K. Salness, J. Walters, V.D. Minh, and A. Wilson. Relationships between ventilation, oxygen uptake, and time during incremental exercise. *Respiration.* 51: 223-231, 1987.
22. Fairshter, R.D., J. Walters, K. Salness, M. Fox, and V.-D. Minh. Comparison of incremental exercise tests during cycle and treadmill ergometry. *Med. Sci. Sports Exerc.* 15(6): 549-554, 1983.
23. Fardy, P.S. and H.K. Hellerstein. A comparison of continuous and intermittent progressive multistage exercise testing. *Med. Sci. Sports Exerc.* 10: 7-12, 1978.
24. Faria, I.E. and B.J. Drommond. Circadian changes in resting heart rate and body temperature, maximal oxygen consumption and perceived exertion. *Ergonomics.* 25: 381-386, 1982.

25. Freedson, P., G. Kline, J. Porcari, R. Hintermeister, R. McCarron, J. Ross, A. Ward, M. Gurry, and J. Rippe. Criteria for defining VO_2 max: a new approach to an old problem. *Med. Sci. Sports Exerc.* 18: S36, 1986.
26. Froelicher, V.F., Jr., H. Brammell, G. Davis, I. Noguera, A. Stewart, and M.C. Lancaster. A comparison of three maximal treadmill exercise protocols. *J. Appl. Physiol.* 36: 720-725, 1974.
27. Gibson, T.M., M.H. Harrison, and R.M. Wellicome. An evaluation of a treadmill work test. *Brit. J. Sports Med.* 13: 6-11, 1979.
28. Gleser, M., D. Hortsman, and R. Mello. The effect on $\text{VO}_{2\text{max}}$ of adding arm work to maximal leg work. *Med. Sci. Sports.* 6: 104-107, 1973.
29. Harrison, M.H., G.A. Brown, and L.A. Cochrane. Maximal oxygen uptake: its measurement, application, and limitations. *Aviation, Space, and Environmental Medicine.* 51: 1123-1127, 1980.
30. Henrickson, J. and J.S. Reitman. Time course of changes in human skeletal muscle succinate dehydrogenase and cytochrome oxidase activities and maximal oxygen uptake with physical activity and inactivity. *Acta Physiol. Scand.* 99: 91-97, 1977.
31. Hermansen, L. and B. Saltin. Oxygen uptake during maximal treadmill and bicycle exercise. *J. Appl. Physiol.* 26: 31-37, 1969.
32. Hill, A.V. and H. Lupton. Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quart. J. Med.* 16: 135-171, 1923.
33. Howley, E.T. and D.R. Bassett, Jr. Maximal oxygen uptake: "classical" versus "contemporary" viewpoints. *Med. Sci. Sports Exerc.* 29(5): 591-603, 1997.
34. Issekutz, B., Jr. and K. Rodahl. Respiratory quotient during exercise. *J. Appl. Physiol.* 16: 606-610, 1961.
35. Katch, V.L., S. Sady, and P. Freedson. Biological variability in maximum aerobic power. *Med. Sci. Sports Exerc.* 14: 21-25, 1982.
36. Katz, A. and K. Sahlin. Role of oxygen in regulation of glycolysis and lactate production in human skeletal muscle, in *Exercise and Sport Sciences Reviews*, K.B. Pandolf, Editor. 1990, Williams & Wilkens: Baltimore. pp. 1-28.

37. Klausen, K., B. Andersen, and I. Pelle. Adaptive changes in work capacity, skeletal muscle capillarization and enzyme levels during training and detraining. *Acta Physiol. Scand.* 113: 9-16, 1981.
38. Klausen, K., H. Secher, J.P. Clausen, O. Hartling, and J. Trap-Jensen. Central and regional circulatory adaptations to one-leg training. *J. Appl. Physiol.: Respirat. Environ. Exerc. Physiol.* 52: 976-983, 1982.
39. Londeree, B.R. and M.L. Moeschberger. Influence of age and other factors on maximal heart rate. *J. Cardiac Rehabil.* 4: 44-49, 1984.
40. Maksud, M.G. and K.D. Coutts. Comparison of a continuous and discontinuous graded treadmill test for maximal oxygen uptake. *Med. Sci. Sports.* 3: 63-65, 1971.
41. Maritz, J.S., J.S. Morrison, J. Peter, N.B. Strydom, and C.H. Wyndham. A practical method of estimating an individual's maximum oxygen intake. *Ergonomics.* 4: 97-122, 1961.
42. McArdle, W.D., F.I. Katch, and G.S. Pechar. Comparison of continuous and discontinuous treadmill and bicycle tests for max VO_2 . *Med. Sci. Sports.* 5: 156-160, 1973.
43. McConnell, T.R. Practical considerations in the testing of $\text{VO}_{2\text{max}}$ in runners. *Sports Med.* 5: 57-68, 1988.
44. McMiken, D.F. and J.T. Daniels. Aerobic requirements and maximum aerobic power in treadmill and track running. *Med. Sci. Sports.* 8: 14-17, 1976.
45. Mitchell, J.H., B.J. Sproule, and C.B. Chapman. The physiological meaning of the maximal oxygen intake test. *J. Clin. Invest.* 37: 538-547, 1958.
46. Myers, J., N. Buchanon, D. Walsh, M. Kraemer, P. McAuley, M. Hamilton-Wessler, and V.F. Froelicher. Comparison of the ramp versus standard exercise protocols. *J. Am. Coll. Cardiol.* 17: 1334-42, 1991.
47. Myers, J., D. Walsh, M. Sullivan, and V. Froelicher. Effect of sampling on variability and plateau in oxygen uptake. *J. Appl. Physiol.* 68(1): 404-410, 1990.
48. Nagle, F., J. Richie, and M. Giese. $\text{VO}_{2\text{max}}$ responses in separate and combined arm and leg air-braked ergometer exercise. *Med. Sci. Sports Exerc.* 16: 563-566, 1984.

49. Niemelä, K., I. Palatsi, and J. Takkunen. The oxygen uptake - work-output relationship of runners during graded exercise cycling exercise: sprinters vs. endurance runners. *Brit. J. Sports Med.* 14(4): 204-209, 1980.
50. Pollock, M.L. Submaximal and maximal working capacity of elite distance runners. Part I: Cardiorespiratory aspects. *Annals of the New York Academy of Sciences.* 301: 310-321, 1977.
51. Pollock, M.L., R.L. Bohannon, K.H. Cooper, J.J. Ayers, A. Ward, S.R. White, and A.C. Linnerud. A comparative analysis of four protocols for maximal treadmill stress testing. *Am. Heart J.* 92: 39-46, 1976.
52. Powers, S.K., J. Lawler, J.A. Demsey, S. Dodd, and G. Landry. Effects of incomplete pulmonary gas exchange of $\text{VO}_{2\text{max}}$. *J. Appl. Physiol.* 75: 1911-1916, 1989.
53. Reilly, T. and G.A. Brooks. Circadian constancy in work stress indices and physiological capacity. *Ergonomics.* 25: 329-330, 1982.
54. Reilly, T. and G.A. Brooks. Investigation of circadian rhythms in metabolic response to exercise. *Ergonomics.* 25: 1093-1107, 1982.
55. Reybrouck, T., G.F. Heigenhauser, and J.A. Faulkner. Limitations to maximum oxygen uptake in arm, leg, and combined arm-leg ergometry. *J. Appl. Physiol.* 75: 1911-1916, 1975.
56. Rivera-Brown, A.M., M.A. Rivera, and W.R. Frontera. Applicability of criteria for $\text{VO}_{2\text{max}}$ in active adolescents. *Ped. Exerc.* 4: 331-339, 1992.
57. Rowell, L.B. Human Cardiovascular Adjustments to Exercise and Thermal Stress. *Physiological Reviews.* 54: 75-103, 1974.
58. Rowell, L.B. *Human Circulation: Regulation During Physical Stress.* New York: Oxford University Press, 1986.
59. Rowland, T.W. Aerobic exercise testing protocols, in *Guidelines for Clinical Laboratory Exercise Testing in Children*, T.W. Rowland, Editor. 1993, Human Kinetics: Champaign, IL. p. 19-42.
60. Rowland, T.W. and L.N. Cunningham. Oxygen uptake plateau during maximal treadmill exercise in children. *Chest.* 101: 485-489, 1992.
61. Saltin, B. Hemodynamic adaptations to exercise. *Am. J. Cardiol.* 55: 42D-47D, 1985.

62. Saltin, B. and P.-O. Åstrand. Maximal oxygen uptake in athletes. *J. Appl. Physiol.* 23(3): 353-358, 1967.
63. Saltin, B. and P.D. Gollnick. Skeletal muscles adaptability: significance for metabolism and performance, in *Handbook of Physiology: Skeletal Muscle*, R.H.A. L.D. Peachy, and S.R. Geiger, Editor. 1983, American Physiological Society: Bethesda, MD. p. 555-631.
64. Scholander, P. Analyzer for accurate estimation of respiratory gases in one-half cubic centimeter samples. *J. Biol. Chem.* 167: 235-250, 1947.
65. Secher, N.H., J.P. Clausen, K. Klausen, I. Noer, and J. Trap-Jensen. Central and regional effects of adding arm exercise to leg exercise. *Acta. Physiol. Scand.* 100: 288-297, 1979.
66. Shephard, R.J. Tests of maximum oxygen intake, a critical review. *Sports Med.* 1: 99-124, 1984.
67. Shephard, R.J., C. Allen, A.J.S. Benade, C.T.M. Davies, P.E. di Prampero, R. Hedman, J.E. Merriman, K. Myhre, and R. Simmons. The maximum oxygen intake. *Bulletin of World Health Organizations.* 38: 757-764, 1968.
68. Stamford, B.A., R. Rowland, and R.J. Moffatt. Effects of severe prior exercise on assessment of maximal oxygen uptake. *J. Appl. Physiol.* 44: 559-563, 1978.
69. Taylor, C. Some properties of maximal and submaximal exercise with reference to physiological variation and the measurement of exercise tolerance. *Amer. J. Physiol.* 142: 200-212, 1944.
70. Taylor, H.L., E. Buskirk, and A. Henschel. Maximal oxygen uptake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8: 73-80, 1955.
71. Weber, K.T., G.T. Kinasewitz, J.S. Janicki, and A.P. Fisman. Oxygen utilization and ventilation during exercise in patients with chronic cardiac failure. *Circulation.* 65: 1213-1223, 1982.
72. Weiner, D.A. and J.A. Lourie. *Human Biology -- A guide to field methods.* Oxford: Blackwell, 1969 .
73. Wojtczak-Jaroszowa, J. and A. Banaskiewicz. Physical work capacity during the day and at night. *Ergonomics.* 17: 193-8, 1974.

74. Wyndham, C.H., N.B. Strydom, J.S. Maritz, J.F. Morrison, J. Peter, and Z.U. Potgieter. Maximum oxygen intake and maximum heart rate during strenuous work. *J. Appl. Physiol.* 14: 927-936, 1959.
75. Yamaji, K., H. Sakamoto, M. Nakaguchi, K. Kitamura, and R.J. Shephard. Biological rhythms of PWC and maximal oxygen intake. *Journal of Human Ergology (Tokyo)*. 10: 213-219, 1981.

APPENDICES

Appendix A
(PAR-Q Questionnaire)

PAR-Q Questionnaire

- | Yes | No | |
|--------------------------|--------------------------|--|
| ☐ | ☐ | 1. Has your doctor ever said you have heart trouble? |
| ☐ | ☐ | 2. Do you frequently have pains in your heart and chest? |
| ☐ | ☐ | 3. Do you often feel faint or have spells of severe dizziness? |
| ☐ | ☐ | 4. Has a doctor ever said your blood pressure is too high? |
| ☐ | ☐ | 5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise? |
| ☐ | ☐ | 6. Is there a good physical reason not mentioned here why you should not follow an activity program if you wanted to? |
| ☐ | ☐ | 7. Are you over age 65 and not accustomed to vigorous exercise? |

If you accurately answered no to all questions, you have reasonable assurance of your present suitability to participate in a graduated exercise test. If you answered yes to one or more questions; if you have not done so recently, consult with your personal physician by telephone or in person BEFORE increasing your physical activity and/or taking part in the study. Tell your physician what questions you answered yes to on the PAR-Q.

Subject's Signature _____
Date _____

Note: Sample PAR-Q Form all subjects completed prior to testing.

*Adopted from the British Columbia Ministry of Health

Appendix B
(Informed Consent)

INFORMED CONSENT

TITLE OF THE STUDY: The effects of stage duration on achieving a plateau in oxygen uptake during a maximal exercise test.

PURPOSE

Maximal oxygen uptake ($\dot{V}O_{2\max}$) is frequently used as an indicator of a person's cardiovascular fitness. $\dot{V}O_{2\max}$ is the body's upper limit for using oxygen to produce energy. As you run on a treadmill and the grade (slope of the running surface) is increased, you will reach $\dot{V}O_{2\max}$. You are invited to participate in a project designed to learn how different types of treadmill tests impact your ability to reach $\dot{V}O_{2\max}$. The purpose of this study is to determine the best test to measure a subject's $\dot{V}O_{2\max}$.

PROCEDURES

If you agree to participate in this study you will report to the Applied Physiology Lab in Room 310 of the HPER Building on four different days for approximately one hour each day. During the first visit you will be shown the equipment and procedures, and age, height, weight will be obtained. Also you will be fitted with a mouthpiece, nose clip, and a heart rate monitor. During the familiarization process you will have an opportunity to run on the treadmill at a variety of inclines and speeds. After you feel comfortable running on the treadmill you will be asked to perform an exercise test to exhaustion. For this test you will only be required to wear the heart rate monitor (not the mouthpiece or the nose clip). After a warm-up of about ten minutes at a speed that keeps your heart rate at approximately 150 beats per minute the test will begin. The speed of the treadmill will be set at 7 mph and the incline (grade) of the treadmill will be increased every minute. You will exercise to exhaustion, and your maximum heart rate will be noted and used as the intensity criterion for the other study trials.

The three remaining tests will use the same procedures as the first session except the incline of the treadmill will be increased either every 30, 60 or 90 seconds. To participate in these tests you should not have eaten for three to four hours prior to the tests, nor have exercised in the previous 12 hours; you are encouraged to drink plenty of water prior to each test session. For this test you will wear headgear supporting a mouth piece, respiratory valve and tubing that will be hooked up to gas analyzers. You will also be wearing a nose clip, and the heart rate monitor used previously. To warm up you will run on the treadmill at 6 mph and the speed will be increased 1/2 mph per minute until you reach eighty percent of the maximum heart rate obtained from the first session (similar to your regular training intensity). After that heart rate is reached you will continue to run at that speed for two additional minutes; you will then rest for ten minutes. After resting you will begin running at the speed that elicited 80% of your maximal heart rate. The incline of the treadmill will be increased at the end of every stage (30s, 60s, or 90s), and you will exercise to exhaustion.

There are several ways to determine that you have exercised to exhaustion. One way is to measure the amount of lactic acid present in your blood. After the three graded exercise tests are performed you will lay supine while your finger is pricked with a lancet and a four drops of your blood are taken for analysis. Safe and sterile techniques will be used in handling the blood samples.

POTENTIAL RISKS OF PARTICIPATION

The exercise tests used in this study may cause some muscle soreness because of their intensity, but it should dissipate within two days. You will be accustomed to exercise so soreness should be minimal. There is a risk of abnormalities of the heartbeat and a heart attack (less than 1 in 10,000)

during maximal testing procedures, though it is very unlikely for someone your age. The risk for young physically active subjects who exercise regularly is even less.

BENEFITS OF PARTICIPATION

You should benefit from knowing your cardiovascular fitness ($\dot{V}O_{2max}$). This information may be helpful in planning modifications to your training fitness program.

CONFIDENTIALITY

Only you, Jim Ford, Dr. Bassett and Dr. Howley will have access to your data. All data will be coded by subject number rather than name and will be kept in a locked file cabinet in room 335 of the HPER Building. The results of the study will be published; however, no publication will contain information that will allow you to be identified.

RIGHT TO ASK QUESTIONS AND/OR TO WITHDRAW FROM THIS INVESTIGATION

If you have any questions or concerns about the research study or your participation in it before or after your consent they can be answered by Jim Ford (Room 144 HPER; 974-8768). If something happens during the study that will not allow you to continue to participate in the study, please contact the investigator. As a volunteer you have the right to withdraw from this study at any time. If you do decide to withdraw from the study you will not be penalized in any way.

CONSENT

By signing this form I am indicating that I have read the above information and consent to participate in this project. I have had the procedures and potential risks explained to me and my questions have been answered to my satisfaction. I understand that I will receive a copy of this consent form to keep.

Participant's Signature: _____ **Date:** _____

Witness Signature: _____ **Date:** _____

Jim Ford
144 HPER
974-8768

Ed Howley
335 HPER
974-1294

David Bassett
343 HPER
974-8766

Appendix C
(Personal Health History Form)

Personal Health History Form

Name: _____ Age: _____

Date: _____

Answer YES or NO to the following questions.

Past History:

	YES	NO	Don't know
Have you ever had:			
Free or easy bleeding (hemophilia)	()	()	()
Rheumatic fever	()	()	()
Heart murmur	()	()	()
High blood pressure	()	()	()
Any heart problems	()	()	()
Varicose veins	()	()	()
Lung disease	()	()	()
Seizures	()	()	()
Irregular heart beat	()	()	()
Bronchitis	()	()	()
Emphysema	()	()	()
Diabetes	()	()	()
Bronchial asthma	()	()	()
Kidney disease	()	()	()
Liver disease	()	()	()
Hay fever	()	()	()
Anemia	()	()	()

Present symptoms review:

	YES	NO	Don't know
Have you recently had:			
Chest pain	()	()	()
Shortness of breath	()	()	()
Heart palpitations	()	()	()
Leg or ankle swelling	()	()	()
Coughing of blood	()	()	()
Low blood sugar	()	()	()
Fainting or dizzy spell	()	()	()
Frequent urination	()	()	()
Blood in urine	()	()	()
Burning sensation	()	()	()
Severe headache	()	()	()
Blurred vision	()	()	()
Difficulty walking	()	()	()
Weakness in arm or leg numbness	()	()	()
Do you smoke?	()	()	()
If so, how many per day? _____			

Appendix D
(Raw data for all subjects)

Table 5. Values from all variables observed for each subject

30 Second Protocol										60 Second Protocol						90 Second Protocol					
Subject	VO _{2max}	Plateau?	Lactate	RER	Grade	Time	VO _{2max}	Plateau?	Lactate	RER	Grade	Time	VO _{2max}	Plateau?	Lactate	RER	Grade	Time			
1	53.67	Y	6.75	1.10	10	5.5	52.75	N	6.98	1.09	7	8	53.71	Y	6.15	1.09	7	12			
2	57.40	Y	10.50	1.25	12	6.5	63.11	Y	8.19	1.15	9	10	64.14	Y	8.66	1.18	8	13.5			
3	57.59	N	9.52	1.23	12	6.5	55.32	Y	7.22	1.16	9	10	54.93	Y	6.19	1.19	7	12			
4	42.0	N	9.27	1.16	8	4.5	36.27	Y	10.60	1.16	6	7	43.09	N	11.10	1.15	5	9			
5	55.36	N	13.70	1.31	10	5.5	55.75	Y	14.0	1.24	9	10	50.93	Y	12.40	1.12	6	10.5			
6	58.92	N	11.50	1.21	9	5.0	57.33	N	11.20	1.18	7	8	51.78	Y	11.70	1.13	6	10.5			
7	50.59	Y	9.07	1.19	8	4.5	53.53	Y	7.20	1.08	6	7	53.23	N	7.60	1.06	5	9			
8	69.64	Y	13.10	1.23	13	7.0	66.35	Y	11.40	1.18	10	11	61.22	Y	9.03	1.1	8	13.5			
9	62.68	Y	8.09	1.21	12	6.5	60.9	Y	6.63	1.07	9	10	53.63	Y	5.55	1.07	8	13.5			
10	65.74	N	11.70	1.21	14	7.5	60.77	N	10.30	1.14	12	13	57.89	N	7.42	1.05	10	16.5			

Note: Values for VO_{2max} are expressed in ml·kg⁻¹·min⁻¹

Values for post-exercise lactate are expressed in mM

Grade and time are expressed in % and minutes respectively

VITA

James Patrick Ford was born in Dover, New Jersey on June 18, 1974. He lived in the same house in Dover until he graduated from Morris Knolls High School in 1992. After graduation he attended Shippensburg University in Pennsylvania, majoring in Biology. While at Shippensburg he worked as a student trainer for two years. He received his Bachelor of Science in 1996. After a much-needed year off from school he decided a change of scenery and more education was necessary. Thus, he decided to pursue a Master of Science in Exercise Physiology from the University of Tennessee, Knoxville. During the second year of his stay in Knoxville he worked as a Graduate Research Assistant, and a Graduate Teaching Assistant. Upon completion of his degree he will pursue a job in Cardiac Rehabilitation, and will reside in Nashville, TN.