Determining the Termination Percentage of Heart Rate Maximum for Submaximal Testing

Julia A. Valentour

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DETERMINING THE TERMINATION PERCENTAGE OF HEART RATE MAXIMUM FOR SUBMAXIMAL TESTING

Julia A. Valentour
DETERMINING THE TERMINATION PERCENTAGE OF HEART RATE MAXIMUM FOR SUBMAXIMAL TESTING

A Thesis

Presented to

the College of Graduate Studies of

Georgia Southern University

In Partial Fulfillment

of the Requirements for the Degree

Master’s of Science

In the Department of

Health and Kinesiology

by

Julia A. Valentour

August 2001
June 25, 2001

To the Graduate School:

This thesis, entitled "Determining the Termination Percentage of Heart Rate Maximum for Submaximal Testing", and written by Julia A. Valentour, is presented to the College of Graduate Studies of Georgia Southern University. I recommend that it be accepted in partial fulfillment of the requirements for the Master's Degree in Health and Kinesiology.

Garth D. Spendiff, Supervising Committee Co-Chair

We have reviewed this thesis and recommend its acceptance:

Matthew A. Williamson, Supervising Committee Co-Chair

W. Kent Guion, Committee Member

James L. McMillan, Committee Member and Acting Department Chair

Accepted for the College of Graduate Studies

G. Lane Van Tassell
Dean, College of Graduate Studies
Dedication

This thesis is dedicated to my parents, James and Mary Ann Valentour, for all of their encouragement and understanding, and for the time and patience of my committee members, especially the two who became fathers during the time that this work was in progress. Thank you for your guidance.
Acknowledgement

The committee I chose for this project was a fantastic array of talent that was able to help in many different ways. Dr. Williamson got the idea into my head that I needed to be gutsy and write a thesis instead of doing an internship. His help with my IRB application was truly a blessing. Dr. Guion led my independent study in the fall semester getting me off to a start by writing my review of literature, and always challenging me to think a little harder. Dr. McMillan helped with his patient and gentle encouragement and listening to my questions and concerns all throughout the process. I am grateful that when he was in his office I knew I could come in and sit down and we could have a productive conversation without feeling like I was interrupting, even though I probably was. Garth Spendiff was a saving grace with his time he devoted and his profound knowledge of exercise testing. Without him I would still be searching for an idea for my thesis right now.

Also, I would like to thank my fellow graduate students, especially Jennifer Hinely and Erin Kenny, who were able to find the bright side of all of my stress and to remind me that it will and can be done.

I would also like to thank the Georgia Southern University Graduate Student Professional Fund and the Department of Health and Kinesiology for their grant money and for helping to make this study possible.
ABSTRACT

DETERMINING THE TERMINATION PERCENTAGE OF HEART RATE MAXIMUM FOR SUBMAXIMAL TESTING

August 2001

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B.A. VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

M.S. GEORGIA SOUTHERN UNIVERSITY

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BACKGROUND: In the Fourth Edition of the American College of Sports Medicine’s Guidelines for Exercise Testing and Prescription (1991), the protocol for the ACSM’s submaximal bike test was to terminate the test at 65-70% of the age predicted maximal heart rate. In the Fifth Edition, this was changed to 85% of the age-predicted maximal heart rate. OBJECTIVES: The purpose of this study was to find out, by using the ACSM submaximal cycle ergometer test (see Appendix A) if the 85% heart rate maximum termination provides a more accurate estimate of maximal aerobic capacity than the 70% heart rate maximum termination. The subjects were thirty volunteer undergraduate students at a mid-sized southeastern university, a group of 16 males and 14 females with a mean age of 19.7 (+/- 1.49) years. METHODS: One ACSM bike protocol test was performed with workloads progressing by 25 or 50 watts every 3 minutes until volitional fatigue. While the submaximal heart rates at 70% and 85% of heart rate max were used to predict VO₂
max using the multistage protocol, each criterion was correlated to the value of the direct measurement of VO$_2$ max and then compared to each other using Fisher's $z$ test. RESULTS: The analysis showed the correlation between the actual measured VO$_2$ max and the estimate at 70% (.503), the actual and the estimate at 85% (.748), and between the two estimates (.503). However, the $z$, transformation did not show a significant difference between the two correlations ($p > .05$). Several variables were entered into a Stepwise multiple regression equation and used to predict the actual VO$_2$ maximum. These variables included age, sex, resting heart rate, systolic blood pressure, diastolic blood pressure, weight, and body fat percentage. All variables were entered into the formula for predicting together with either the estimated VO$_2$ at 70% or the estimated VO$_2$ at 85%. Interestingly, the only variables that were used in each prediction equation were the estimated VO$_2$ at 70 or 85%. The equation using the estimate at 70% showed an adjusted R square value of .227, with a standard error of the estimate of 4.61. This means that only 23% of the estimate can be explained. The adjusted R square value of the 85% estimate was .544, with the standard error of the estimate at 3.54. This has a lower SEE and is a better predictor, but is still only able to explain 54% of the estimated value. CONCLUSION: The conclusion that can be made from this study is that, in assessing the VO$_2$ maximum of a group of apparently healthy college aged males and females, a submaximal exercise test that terminates at 70% of maximal heart rate can be used to predict their actual maximal VO$_2$. 
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Determining the Termination Percentage of Heart Rate
Maximum for Submaximal Testing

In order to live longer and healthier, Americans need to increase their levels of physical activity (Pate, 1995). Exercise testing assists in exercise prescription and is beneficial in determining baseline fitness levels and establishing progress. Some appropriate tests to determine a person’s fitness level include measures of body composition, muscle strength and endurance, flexibility, and cardiorespiratory testing. Although all of these tests are important to measure the different components of fitness, cardiorespiratory testing is one of the most important (Heyward, 1998). Cardiorespiratory testing can predict a person’s overall training status and risk for cardiovascular disease (McKelvie, 1989). The level of cardiorespiratory fitness establishes the efficiency of the aerobic system, or the greatest amount of oxygen that the body can use. This measurement is referred to as the VO$_2$ maximum (Baechle, 1994). VO$_2$ maximum (VO$_2$ max) is defined as the maximal rate for the body to consume oxygen (Foss, 1998). This can be measured by three different methods: submaximal exercise testing, maximal exercise testing, and maximal testing with the direct measurement of expired gases. The direct measurement of expired gases is considered the standard measurement of cardiorespiratory fitness, however, this requires expensive equipment, appropriately trained personnel, and maximal physical exertion from the participant.
(Heyward, 1998, and Hartung, 1993). These requirements are not always available or practical.

The other two methods or processes used to evaluate maximum aerobic capacity are maximal and submaximal exercise testing. Maximal testing requires the patient to exercise until they reach a point of exhaustion or until certain set criteria are met (Lear, 1999). Submaximal tests, which do not require maximal exertion, may be easier and less costly for health/fitness practitioners to perform while still enabling a determination of the subject's fitness level. This type of testing requires less equipment, less technical and clinical expertise to administer, and a lower exertion level on behalf of the participant. Accuracy of submaximal testing is typically determined if there is a strong correlation to the VO\(_2\) max measured from the direct analysis of gases during maximal testing.

To measure this correlation, participants may perform multiple tests in order to determine their actual VO\(_2\) maximum and the VO\(_2\) max that is predicted by submaximal testing. There have been some changes in the last decade over the termination point for submaximal testing. In the Fourth Edition of the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (1991), the protocol for the submaximal bike test terminated the test at 65-70% of the age predicted maximal heart rate. In the Fifth Edition, this was changed to 85% of the maximal heart rate (ACSM 1991, 1995) without an explanation. In Heyward's Advanced Fitness Assessment and Exercise Prescription (1998), it is suggested that more research is needed to support the change in standards. There was one study that was cited that addressed this issue. The study by Greiwe et al. (1995) examined the validity and reliability of the 70% heart rate max test
termination. Fifteen males and fifteen females performed one maximal test on a cycle ergometer while oxygen consumption was measured using a metabolic cart. Two ACSM submaximal bike tests were then performed by each participant, both terminating at the end of the fourth stage or 65-70% age predicted heart rate maximum. The researchers found as much as 25% overestimation of VO₂ max for the submaximal tests. The standard error of estimate (SEE) values expressed as a percentage of the mean were high, suggesting that the ACSM bike test at 70% was not acceptable as an accurate assessment of VO₂ max (Greiwe, 1995). One reason for this lack of accuracy may have been due to the termination criteria of 70% which may be too low to determine differences in fitness levels (Greiwe, 1995). However, Greiwe et.al did not compare the 70% to the 85% heart rate termination, so the correlation between the two submaximal tests is still unknown as well as the correlation between the 85% heart rate termination criteria and the maximal cycle test as suggested in ACSM (ACSM, 1995).

Therefore, the purpose of this study was to determine, by using the ACSM submaximal cycle ergometer test, if the 85% heart rate maximum termination provided a more accurate estimate of VO₂ max, than the 70% heart rate maximum termination.

Methods

Participants

Participants were thirty volunteer undergraduate students at a mid-sized southeastern university who were enrolled in beginning and intermediate volleyball classes. The sample included 16 males and 14 females with a mean age of 19.7, +/- 1.5 years. All of
these participants signed informed consent forms and filled out a medical history form. All were considered apparently healthy with no orthopedic problems that could affect the results of their tests and all had normal resting values for heart rate and blood pressure (ACSM, 1995). Approval was granted for the use of human subjects from the University’s Internal Review Board.

**Procedures**

When the participants signed up for testing times, pre-test instructions as outlined by ASCM’s Guidelines for Exercise Testing (ACSM, 2000) were issued to ensure appropriate test preparation. This included being well rested, well hydrated, and to avoid eating, drinking, or smoking within three hours of the test. Subjects were asked at the time of testing if they were able to comply with these guidelines, and all who had not done so were rescheduled. Informed consent and health history forms were collected. Subjects who had any history of ankle, knee, or hip problems were excluded from the study, as well as anyone who met the absolute or relative contraindications to exercise testing as outlined in the ACSM's guidelines (ACSM, 1995). These contraindications include unstable angina, ventricular arrhythmias, or acute infections. A short exercise questionnaire was given to determine if the participant was considered very active or not. “Very active” as defined by Heyward (1998) described a person who regularly participated in aerobic exercise for 20 minutes, 3 days per week. While seated, Polar heart monitors (Polar CIC, Inc., Port Washington, NY) were attached to each participant as per manufacturer’s instructions to determine resting heart rates and later to ascertain exercise heart rates. After the completion of the paper work, blood pressure was assessed.
using ACSM standards (ACSM, 1995) with a mercury sphygmomonometer after the subject had been seated quietly for five minutes. The cuff was wrapped firmly around the right upper arm with the stethoscope bell placed over the brachial artery and inflated to at least 200 mm Hg. The first and fifth Korotkoff sounds were recorded. In accordance with the ACSM's (1995) relative contraindications, blood pressure values of > 200 mm Hg systolic or >110 mm Hg diastolic prevented the subject's further participation.

Body weight, resting blood pressure, resting heart rate, and body fat percentages were determined prior to testing. Skinfolds were measured using Lange calipers and body density was determined using a three-site equation for men (Jackson & Pollock, 1978) and for women (Jackson et. al, 1980). The body density was then converted to body fat percentage using population-specific formulas which take into account the age, sex, and ethnicity of the individual (Heyward, 1998).

Aerobic capacity testing consisted of the direct measurement of expired gases, accomplished using a MedGraphics CardiO2 metabolic cart (Medical Graphics Corporation, St. Paul, Minnesota). A complete calibration was performed at the beginning of each day and another automatic calibration was done just prior to each test as suggested by the user’s manual (Medical Graphics Corporation, 1992). The mouthpiece and pneumotach mouthpiece which are placed in the participant’s mouth to collect the gases were cleaned and replaced, respectively, after each person’s use. A Monark cycle ergometer (Quinton Instrument Company, Bothell, Washington) was used and calibrated at the beginning of all testing as determined by the manual. Seat height was adjusted so that the knee was just slightly bent at the down position of the pedal. An
American Heart Association Advanced Cardiac Life Support Certified administrator or another faculty member was present during all tests.

According to the guidelines of the ACSM cycle ergometer test (Heyward, 1998), different workloads were assigned depending on the subject’s weight and activity status. Based on this, a protocol (A, B, or C) was assigned to each participant prior to testing. The test began with a 15 watt warm up for three minutes. Participants were instructed to maintain 60 RPM throughout the entire test. During the test, oxygen consumption was measured breath by breath and recorded every 30 seconds by the MedGraphics metabolic cart. The flow meter used for the testing was calibrated before every test in accordance with the manufacturer’s instructions.

The stages of the test consisted of progressively increasing workloads (either 25 or 50 watts) as determined by the protocol. After the first minute and a half of each stage, the rating of perceived exertion was monitored using the Borg 6-20 scale (Borg, 1982). At the end of the second minute, heart rate and blood pressure were recorded. Heart rate was taken again during the last 15 seconds of the third minute. If both of the heart rates taken in a stage were within six beats, the researchers assumed that a steady heart rate had been reached (Heyward, 1998). The test would then progress to the next workload for the beginning of a new stage. If the heart rates were not within six beats, the stage was extended an additional minute or more until steady heart rate was reached. Workloads continued to increase until volitional fatigue of the subject, or until the researchers terminated the test because the participant could not maintain 60 RPM as required. After each test, participants were monitored during a 4-minute cool down at 15 watts.
Data Analysis

Several factors served as criteria for determining a maximum effort. A heart rate within 10% of age predicted maximum (220 minus age) was considered one of these criteria. A final rating of perceived exertion of 17 or greater was also a determining factor. A respiratory exchange ratio of 1.15 or greater, or a plateau of VO$_2$ of 150 milliliters per kilogram per minute or less with an increase in workload also served as indicators that a maximal effort was given. If at least two of these four criteria were met, the test was considered a maximal effort (ACSM, 2000). The submaximal heart rates at 70% and 85% of heart rate max were used to calculate VO$_2$ maximum using the multistage model (Heyward, 1998). This model uses the workloads and heart rates from the last two stages before the termination point is reached. The slope (b) is calculated by dividing the difference in submaximal workloads (expressed as VO$_2$) by the difference in heart rates. VO$_2$ maximum is then calculated by the formula:

$$\text{VO}_2 \text{ maximum} = \text{SM}_2 + b (HR \text{ max} - HR_2)$$

Where: $\text{SM}_2$ = the submaximal workload at the last completed stage before termination; b = the slope; and $HR_2$ = the steady heart rate recorded at this stage (Heyward, 1998).

The open circuit spirometry analysis provided the measurement of VO$_2$ maximum that was considered the standard. Estimates of VO$_2$ max using 70% and 85% heart rate maximum as termination criteria were each entered into a multivariate correlation with the value of the direct measurement. These correlations were then compared by using Fisher’s $z_r$ Test. This is done by converting each correlation ($r_1$ and $r_2$) to $z_r$ by using a
conversion table (Ferguson, 1981). The standard error is calculated by \( s_{z} = 1 \sqrt{N-3} \). The difference found between the two predictions was tested for significance.

\[
Z = \frac{z_{1} - z_{2}}{\sqrt{1/(N1 - 3) + 1/(N2 - 3)}}
\]

For significance at the .05 level, the value obtained here must be above 2.58, and was no greater than 1.53.

A multiple regression analysis was also performed to determine if other variables are necessary or more important in the prediction of \( \text{VO}_2 \) maximum than a submaximal estimate. Variables entered into the prediction included age, gender, resting heart rate, systolic blood pressure, diastolic blood pressure, weight, body fat percentage, activity status, and the estimated \( \text{VO}_2 \) maximum at the 70% heart rate termination. This was done again using the same variables but substituting the estimate from the 85% heart rate termination. All statistical analyses were done using SPSS version 10.0 (SPSS Inc., Chicago, Illinois).

**Results**

Thirty participants were used for the study, 16 male (age = 20.19 +/- 1.72) and 14 female (age = 19.14 +/- 0.95). The mean actual \( \text{VO}_2 \) max for all of the participants was 32.75 +/- 5.25 ml/kg/min. The estimated \( \text{VO}_2 \) max from the 70% termination was 40.36 +/- 8.12 ml/kg/min for all subjects, and for the 85% termination was 35.81 +/- 4.87 ml/kg/min (For descriptive statistics, see Table I).
The analysis showed a significant correlation between the actual measured VO$_2$ max and the estimate at 70% (.503), the actual and the estimate at 85% (.748), and between the two estimates (.503). The Fisher's z Test calculation result was 1.53, which did not show a significant difference between the two correlations ($p > .05$).

The estimates of VO$_2$ maximum for both 70 and 85% terminations were higher than the actual VO$_2$ for both males and females. The mean estimated VO$_2$ for 70% was 40.91, +/- 8.09 ml/kg$^\dagger$/min$^\dagger$ for the males and 39.74, +/- 8.42 ml/kg$^\dagger$/min$^\dagger$ for the females. The method terminating at 70% tended to overpredict the actual measurement by an average of 23% for all subjects. This was consistent with both sexes: the males were overpredicted by 24% and the females by 23%. The 85% predictions were 35.59 +/- 5.76 ml/kg$^\dagger$/min$^\dagger$ for the males and 36.06 +/- 3.80 ml/kg$^\dagger$/min$^\dagger$ for the females. The method terminating at 85% also overpredicted the actual measurement, but only by an average of 9% for all subjects (7% for males, 12% for females) (see Table III).

The active subject group consisted of 11 males and 9 females. The average VO$_2$ of this group was 33.65, +/- 5.29 ml/kg$^\dagger$/min$^\dagger$ (see Table II). Inactive subjects consisted of 5 males and 5 females, and had an average VO$_2$ of 30.95, +/- 4.93 ml/kg$^\dagger$/min$^\dagger$.

All of the resting measurements were used as variables and entered into a Stepwise multiple regression equation and used to predict the actual VO$_2$ maximum. These variables included age, sex, resting heart rate, systolic blood pressure, diastolic blood pressure, weight, and body fat percentage. The estimated VO$_2$ at 70% and the estimated VO2 at 85% were each entered into separate equations with the other variables. The only common variable to both regression analyses was the estimated VO$_2$ at each end point.
Age was used in the multistage formula to predict maximal heart rate, but alone did not help predict \( VO_2 \max \). The equation using the estimate at 70% showed an adjusted R square value of \(.227\) with a standard error of the estimate of \(4.61\). This meant that only 23% of the estimated \( VO_2 \max \) can be explained (or predicted) by the submaximal test ending at 70%. The adjusted R square value of the 85% estimate was \(.544\), with the standard error of the estimate at \(3.54\).

The categories used for this evaluation were: Superior, Excellent, Good, Fair, and Poor (Heyward, 1998). For males, a superior rating was a \( VO_2 \) maximum of \(49 \text{ ml/kg}^{\prime} \text{min}^{-1}\) and above, and for females \(42 \text{ ml/kg}^{\prime} \text{min}^{-1}\) and above. Excellent consisted of a rating of \(45-48 \text{ ml/kg}^{\prime} \text{min}^{-1}\) for males and \(38-41 \text{ ml/kg}^{\prime} \text{min}^{-1}\) for females. For the excellent and superior categories, each only contained one female (3% of the total). Of the two females, the one that was ranked excellent considered herself inactive, while the superior female was very active. The good category of \( VO_2 \) maximum for males was \(42-44 \text{ ml/kg}^{\prime} \text{min}^{-1}\) and \(35-37 \text{ ml/kg}^{\prime} \text{min}^{-1}\) for females. The good category contained 3 subjects, which was 10% of the total, with two reporting heavy activity and one sedentary. The fair category (\(38-41 \text{ ml/kg}^{\prime} \text{min}^{-1}\) for males, \(32-34 \text{ ml/kg}^{\prime} \text{min}^{-1}\) for females) contained 4 subjects, 13% of the total. All of these subjects reported being very active. \( VO_2 \) max for most of the subjects was in the poor category. For the males, this was a \( VO_2 \) of \(37 \text{ ml/kg}^{\prime} \text{min}^{-1}\) or below, or \(31 \text{ ml/kg}^{\prime} \text{min}^{-1}\) or below for the females. This group included 12 of the 16 males and 9 of the 14 females, which was 70% of the total group. This consisted of both active and inactive subjects.
For two of the tests, the same stages had to be used in the multistage formula to calculate the VO₂ max at both 70 and 85% maximal heart rate. Therefore, the same VO₂ max was estimated for each equation. These were added to the data and a second correlation was done. The addition of these two tests increased the correlation of the 70% termination (from .503 to .534) and the 85% termination (.748 to .759). Using this additional data did not affect the outcome of the Fisher’s z, Test. The result was 0.93, which still showed no significant difference (p > .05) between the correlations of 70% versus 85%.

Conclusions/Discussion

In this study, the estimated VO₂ max maximum predicted from the termination point of 70% maximum heart rate (40.36, +/- 8.12 ml/kg-l/min-1) was significantly correlated (r = .503, p = .005) to the actual VO₂ max that was measured (32.75, +/- 5.25 ml/kg-l/min-1). The addition of further stages to reach the 85% maximum (estimated VO₂ max maximum 35.81, +/- 4.87 ml/kg-l/min-1) yielded a correlation of .748 (p = .001).

Other studies, when comparing submaximal to maximal VO₂ measurements, found similar correlations. The correlation of the actual VO₂ max and the estimate at 85%, (.748), was similar to the findings of Hartung et. al (1995) who found a correlation of .72 when comparing submaximal cycle ergometer tests to a maximal cycle test. The test used in the Hartung study did not terminate at 85% maximal heart rate, but rather terminated when steady state was reached, at the end of 6 or 9 minutes (no more than 10 minutes total) (Hartung et. al, 1995).
Similarly, for the Astrand-Rhyming (A-R) Cycle Ergometer test, the correlation reported by Astrand (1960) between the original submax test and the actual measured VO2 max was .71. This increased to a .78 when the age correction factor was included to account for a lower heart rate maximum with age. Another similar finding is by Teraslinna et. al (1966), who found a correlation of the A-R test to actual VO2 to be .69, and with the age correction factor to be .92 (Noonan, 2000). Other modes of VO2 max estimation like the Canadian Aerobic Fitness Test (CAFT) have also correlated highly with a maximal treadmill test (r = .90), but a large standard error (13%) may lead to the misclassification of some subjects. (Cox, 1992).

The correlations between submaximal and maximal testing in this study are low as compared to other research involving statistical regression models. For example, multiple linear regression was used in the study by Storer et. al (1990). The independent variables of body weight, age, and cycling test duration were used to predict VO2 max with a correlation of .93-.94. Kline et. al (1987) included the predictor variables age, weight, sex, track walk time, and heart rate to estimate VO2 max with a coefficient of .93 and a cross validation coefficient of .92.

In fact, even non-exercise tests using regression models have been found to have higher correlations to maximum than in the present study. George et. al (1997) used questionnaires to develop a nonexercise regression model based on variables such as: body mass index, sex, the subject’s perceived functional ability to walk, jog, or run distances, and their habits of physical activity. Used with 100 physically active college students, the researchers reported a correlation of .85 with minimal statistical shrinkage.
from cross validation. Similarly, a non-exercise regression model developed by Heil et al. (1995) using factors such as: percent body fat, sex, activity code (0-7), age, and age was able to predict maximal VO₂ with correlation coefficients ranging from .85-.88. These questionnaire methods of determining VO₂ max are much simpler, more efficient, and easier on the part of both researchers and participants than the methods using submaximal testing.

Although the two estimates had a moderate correlation to each other (.503), the Z test showed no significant difference. Both estimates of VO₂ max tended to overpredict the direct measurement of VO₂ max obtained from gas analysis, although this was not statistically significant. Greiwe et. al (1995) found a similar overestimation of the actual VO₂ max in 85% of all the trials performed. The percent error between the estimated VO₂ max terminating at 70% and the actual measurement was found to be 25.7%, similar to the 23% error found in this study. Likewise, Hartung et. al (1995) found that submaximal cycle ergometer tests significantly overestimated VO₂ max when compared to both treadmill and cycle maximal tests (8.5% and 18.5%, respectively). A possible reason cited by Greiwe et.al (1995) for this is the variation of the age-predicted heart rate maximum as compared to the actual. In the Greiwe study, the actual heart rate maximum was found to be lower than predicted for 23% of the participants. The use of the actual heart rate maximum decreased the estimated VO₂ maximum, but the difference was not significant (Greiwe et. al, 1995).

Some studies, such as McMurray et. al (1998) compare submaximal cycle ergometer tests to a maximal treadmill test. A factor influencing the results in the present study
could be the use of this protocol as a maximal cycle test to determine actual VO₂ max. The ACSM bike test has only been validated for use as a submaximal test. Therefore, the direct measurement of VO₂ max, considered in this study to be the "actual" measurement, may not be accurate as this testing procedure has not been validated. The assumption of the protocol as a max test, in combination with the limited cycling experience of the participants, could have resulted in more difficulty achieving a high rating of VO₂ maximum due to the specific lower extremity fatigue that many experienced. Of the thirty participants in the study, 26 reported the main reason they stopped was "my legs were tight" or "my legs felt like they were burning". Only four of the subjects reported that having difficulty breathing was their sole reason for stopping. This localized leg pain may have prevented these other 26 subjects from reaching higher VO₂ maximums, a common finding in cycle ergometry studies (Glassford, 1965). The evidence for this, as seen from the data collected, is that in almost all cases the VO₂ values continued to climb throughout the entire test and did not plateau. The intense fatigue in the legs with only mild stress in the upper body might not invoke as large a response from the cardiorespiratory system. Treadmill running, which evokes a more general fatigue, may invoke a greater response and therefore a greater VO₂ maximum (Glassford, 1965). For a group of 37 healthy women aged 19-47 years, Hartung et. al (1995) found a greater mean VO₂ for the treadmill than the cycle ergometer. The measurement of actual VO₂ maximum on the treadmill was significantly higher (9.3%) than that measured on the cycle (Hartung et. al, 1995).
Other studies have also shown a limitation in the ability to achieve VO\textsubscript{2} maximum due to the specific musculature involved. For the majority of the subjects in the study by Cox et al. (1992), localized leg fatigue was believed to be a limiting factor in performing the Canadian Aerobic Fitness (step) test, and the treadmill maximal testing resulted in significantly higher VO\textsubscript{2} maximums than the maximal step test.

This study went a step further than Griewe (1995), in that the factors cited by Greiwe as possible explanations for low correlations were corrected. The duration of the stages was increased (3 minutes as compared to 2 minutes), and the termination percentage of heart rate maximum was increased to include an 85% termination. According to Greiwe et al. (1995) the termination point of 70% failed to be reliable and should not be used when an accurate measurement is required. Despite the changes that were made, however, the results of the present study also show a low correlation of the 70% to maximum (.503). With the 85% termination, although a stronger correlation existed (.748), the Fisher’s z test showed no significant difference from the 70% termination and therefore it should be considered the same. Because the statistical analysis held up the null hypothesis that there is no statistical difference in the values of the two estimates, this leads to the conclusion that the 85% termination is not different (and therefore not more accurate) than 70%.

As stated by Edgren et al (1976), submaximal tests are best used for comparisons of the same individual and not for accurate measurement of aerobic capacity. The estimation of VO\textsubscript{2} maximum from submaximal testing will always be slightly different from the actual measured values. This is inherent to the process due to the assumptions
that must be made for submaximal testing. However, there are methods by which one
can control the threats to internal and external validity. Randomization of the sample can
control for many possible errors with regard to both types of validity (Thomas, 1996).

The internal validity was controlled for by having the subjects serve as their own
control group; that is, each subject performed all three tests in one. Because all
measurements were calculated from one single trial, there were no effects from history,
maturational, or experimental mortality. Instrumentation was calibrated per
manufacturer's instructions to ensure accuracy. However, the ACSM cycle ergometer
protocol has not been validated for use as a maximal test. Selection bias is another factor
that may have affected the results of this study. The incentive offered for participation
included a free fitness evaluation as well as a credit for one class absence. Those
participants who may have been the most willing to volunteer were those who have
missed the most classes and needed to make up an absence to avoid receiving a low
grade. This type of incentive may have appealed to the less motivated students and a
relationship may exist between lower fitness levels and lower motivation in activity
classes.

In this study, a convenient sample was used. Because there was a tendency for the
fitness scores to cluster around the lower end of the scale, this group may not represent
the whole university or the average participant in activity classes. This weakens the
external validity of this study.

More research is needed on the subject of submaximal exercise test termination to
determine if a randomized sample, with fitness levels more representative of the average
population, shows a similar correlation between the two estimates and the actual VO$_2$ max. Missing from the literature is data supporting the ACSM's decision to change the heart rate end point for submax testing from 70% to 85%. Knowing the basis for this change, and knowing why other percentages of heart rate maximum were not used, will help to increase the understanding of the methods for predicting VO$_2$ max.
REFERENCES


### Table I
Descriptive Statistics
Means and Standard Deviations

<table>
<thead>
<tr>
<th>Variable</th>
<th>All subjects</th>
<th>Males (n = 16)</th>
<th>Females (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual VO(_2) (ml/kg(^{-1})/min(^{-1}))</td>
<td>32.75/5.25</td>
<td>33.11/5.22</td>
<td>32.34/5.44</td>
</tr>
<tr>
<td>Est VO(_2) 70% (ml/kg(^{-1})/min(^{-1}))</td>
<td>40.36/8.12</td>
<td>40.91/8.09</td>
<td>39.74/8.42</td>
</tr>
<tr>
<td>Overestimation from the 70% termination</td>
<td>+ 23%</td>
<td>+ 24%</td>
<td>+ 23%</td>
</tr>
<tr>
<td>Est VO(_2) 85% (ml/kg(^{-1})/min(^{-1}))</td>
<td>35.81/4.87</td>
<td>35.59/5.76</td>
<td>36.06/3.80</td>
</tr>
<tr>
<td>Overestimation from the 85% termination</td>
<td>+ 9%</td>
<td>+ 7%</td>
<td>+ 12%</td>
</tr>
<tr>
<td>Resting HR (Beats per minute)</td>
<td>74.57/9.64</td>
<td>74.69/12.49</td>
<td>74.43/5.23</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>111.67/8.99</td>
<td>115.88/7.32</td>
<td>106.86/8.47</td>
</tr>
<tr>
<td>Diastolic BP (MmHg)</td>
<td>73.00/6.70</td>
<td>76.25/5.56</td>
<td>69.29/6.06</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>71.68/12.90</td>
<td>79.39/9.80</td>
<td>62.86/10.17</td>
</tr>
<tr>
<td>Body Fat %</td>
<td>16.04/7.12</td>
<td>11.44/5.34</td>
<td>21.30/4.93</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>19.70/1.49</td>
<td>20.19/1.72</td>
<td>19.14/0.95</td>
</tr>
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<td>Variable</td>
<td>Active Subjects</td>
<td>Inactive Subjects</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(male = 11, female = 9)</td>
<td>(male = 5, female = 5)</td>
<td></td>
</tr>
<tr>
<td>Actual VO$_2$ (ml/kg$^{-1}$/min$^{-1}$)</td>
<td>33.65/5.29</td>
<td>30.95/4.93</td>
<td></td>
</tr>
<tr>
<td>Est VO$_2$ 70% (ml/kg$^{-1}$/min$^{-1}$)</td>
<td>42.77/8.48</td>
<td>35.55/4.71</td>
<td></td>
</tr>
<tr>
<td>Est VO$_2$ 85% (ml/kg$^{-1}$/min$^{-1}$)</td>
<td>37.25/4.55</td>
<td>32.93/4.35</td>
<td></td>
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<tr>
<td>Resting HR (Beats per minute)</td>
<td>72.30/6.09</td>
<td>79.10/13.67</td>
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</tr>
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<td>Systolic BP (mmHg)</td>
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<td>109.20/9.99</td>
<td></td>
</tr>
<tr>
<td>Diastolic BP (mmHg)</td>
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<td>72.60/5.42</td>
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<tr>
<td>Weight (kg)</td>
<td>72.83/12.36</td>
<td>69.38/14.31</td>
<td></td>
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<tr>
<td>Body Fat %</td>
<td>16.45/7.79</td>
<td>15.21/5.82</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>19.55/1.43</td>
<td>20.00/1.63</td>
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</tr>
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### Table III
Percent Differences in Actual and Estimated VO$_2$ maximum

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Sex</th>
<th>Actual VO$_2$ ml/kg$^{-1}$/min$^{-1}$</th>
<th>Estimated VO$_2$ at 70% ml/kg$^{-1}$/min$^{-1}$</th>
<th>% difference</th>
<th>Estimated VO$_2$ at 85% ml/kg$^{-1}$/min$^{-1}$</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>42.63</td>
<td>55.16</td>
<td>+ 29.39%</td>
<td>47.67</td>
<td>+ 11.82%</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>40.40</td>
<td>37.94</td>
<td>- 6.09%</td>
<td>35.68</td>
<td>- 11.68%</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>33.50</td>
<td>47.70</td>
<td>+ 42.39%</td>
<td>40.16</td>
<td>+ 19.88%</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>34.40</td>
<td>45.72</td>
<td>+ 32.91%</td>
<td>37.02</td>
<td>+ 7.62%</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>30.70</td>
<td>35.29</td>
<td>+ 14.95%</td>
<td>30.87</td>
<td>+ 0.55%</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>32.10</td>
<td>30.95</td>
<td>- 3.58%</td>
<td>30.50</td>
<td>- 4.98%</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>34.30</td>
<td>33.85</td>
<td>- 1.31%</td>
<td>34.96</td>
<td>+ 1.92%</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>29.60</td>
<td>39.54</td>
<td>+ 33.58%</td>
<td>32.74</td>
<td>+ 10.61%</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>30.30</td>
<td>37.31</td>
<td>+ 23.14%</td>
<td>36.70</td>
<td>+ 21.12%</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>37.70</td>
<td>37.85</td>
<td>+ 0.40%</td>
<td>39.68</td>
<td>+ 5.25%</td>
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<tr>
<td>11</td>
<td>M</td>
<td>31.60</td>
<td>48.28</td>
<td>+ 52.78%</td>
<td>35.49</td>
<td>+ 12.31%</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>29.10</td>
<td>44.94</td>
<td>+ 54.43%</td>
<td>34.09</td>
<td>+ 1.71%</td>
</tr>
<tr>
<td>13</td>
<td>F</td>
<td>27.70</td>
<td>45.03</td>
<td>+ 62.56%</td>
<td>37.28</td>
<td>+ 34.58%</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>30.60</td>
<td>34.47</td>
<td>+ 12.65%</td>
<td>29.16</td>
<td>- 4.71%</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>44.80</td>
<td>65.24</td>
<td>+ 45.63%</td>
<td>42.62</td>
<td>- 4.87%</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>31.10</td>
<td>37.82</td>
<td>+ 21.61%</td>
<td>38.07</td>
<td>+ 22.41%</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>35.30</td>
<td>35.79</td>
<td>+ 1.39%</td>
<td>40.05</td>
<td>+ 13.46%</td>
</tr>
<tr>
<td>18</td>
<td>F</td>
<td>28.00</td>
<td>39.92</td>
<td>+ 42.57%</td>
<td>32.40</td>
<td>+ 15.71%</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>29.70</td>
<td>37.67</td>
<td>+ 26.84%</td>
<td>36.65</td>
<td>+ 23.40%</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>30.70</td>
<td>37.55</td>
<td>+ 22.31%</td>
<td>37.53</td>
<td>+ 22.25%</td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>38.30</td>
<td>42.50</td>
<td>+ 10.97%</td>
<td>43.90</td>
<td>+ 14.62%</td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>24.30</td>
<td>39.33</td>
<td>+ 61.85%</td>
<td>30.61</td>
<td>+ 25.97%</td>
</tr>
<tr>
<td>23</td>
<td>M</td>
<td>34.20</td>
<td>31.86</td>
<td>- 6.84%</td>
<td>31.16</td>
<td>- 8.89%</td>
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<tr>
<td>24</td>
<td>M</td>
<td>37.80</td>
<td>38.30</td>
<td>+ 1.32%</td>
<td>39.08</td>
<td>+ 3.39%</td>
</tr>
<tr>
<td>25</td>
<td>F</td>
<td>33.30</td>
<td>32.73</td>
<td>- 1.71%</td>
<td>38.73</td>
<td>+ 16.31%</td>
</tr>
<tr>
<td>26</td>
<td>M</td>
<td>23.90</td>
<td>44.14</td>
<td>+ 84.69%</td>
<td>26.08</td>
<td>+ 9.12%</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>28.70</td>
<td>37.30</td>
<td>+ 29.97%</td>
<td>30.15</td>
<td>+ 5.05%</td>
</tr>
<tr>
<td>28</td>
<td>M</td>
<td>31.50</td>
<td>31.04</td>
<td>- 1.46%</td>
<td>37.37</td>
<td>+ 18.63%</td>
</tr>
<tr>
<td>29</td>
<td>M</td>
<td>41.20</td>
<td>56.34</td>
<td>+ 36.75%</td>
<td>38.59</td>
<td>- 6.33%</td>
</tr>
<tr>
<td>30</td>
<td>F</td>
<td>25.10</td>
<td>29.24</td>
<td>+ 16.49%</td>
<td>29.21</td>
<td>+ 16.37%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>32.75/5.25</td>
<td>40.36/8.12</td>
<td>+ 23%</td>
<td>35.81/4.87</td>
<td>+ 9%</td>
</tr>
</tbody>
</table>
25

Estimated VO2 Maximum from 70% and 85% Heart Rate Maximum Termination

Figure 1
Graphing Method of Calculating VO2 Maximum
(Participant’s Weight in Kg: 73.4)

Calculations for the Estimation of VO2 Maximum from 70% and 85% Heart Rate Maximum (Graphing Method):

70% Termination:

Max Workload: 325

\[ VO_2 = (325 \times 6) \times 1.9 + 260 + (73.4 \times 3.5) \]

\[ = (1950) \times 1.9 + 260 + (256.9) \]

\[ = 3705 + 516.9 \]

\[ = 4221.9 \]

\[ \frac{4221.9}{73.4} = 57.52 \text{ mg/kg/min}^{-1} \]

85% Termination:

Max Workload: 260

\[ VO_2 = (260 \times 6) \times 1.9 + 260 + (73.4 \times 3.5) \]

\[ = (1560) \times 1.9 + 260 + (256.9) \]

\[ = 2964 + 516.9 \]

\[ = 3480.9 \]

\[ \frac{3480.9}{73.4} = 47.42 \text{ mg/kg/min}^{-1} \]
A Comparison of the Actual Measured VO2 max and the Estimate from 70% Max Heart Rate

\[ \text{est70} = 14.84 + 0.78 \times \]

\[ \text{R-Square} = 0.25 \]

Figure 2
A Comparison of the Actual Measured VO2 max and the Estimate from 85% Max Heart Rate

Linear Regression with 95.00% Mean Prediction

\[ \text{est85} = 13.07 + 0.69 \times \]

R-Square = 0.56

Figure 3
APPENDIX A

THE ACSM CYCLE ERGOMETER TEST

The protocol is determined by the subject’s weight and activity status. A very active person is defined as one who performs aerobic exercise for 20 minutes, 3 days per week.

Selection Criteria:

<table>
<thead>
<tr>
<th>BW in kg</th>
<th>Very Active:</th>
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<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>&lt; 73</td>
<td>A</td>
</tr>
<tr>
<td>74-90</td>
<td>A</td>
</tr>
<tr>
<td>&gt; 91</td>
<td>B</td>
</tr>
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</table>

Test Protocol:

<table>
<thead>
<tr>
<th>Stages (3 min each)</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 w (150 kgm)</td>
<td>25 w (150 kgm)</td>
<td>50 w (300 kgm)</td>
<td>50 w (300 kgm)</td>
</tr>
<tr>
<td>50 w (300 kgm)</td>
<td>50 w (300 kgm)</td>
<td>100 w (600 kgm)</td>
<td>100 w (600 kgm)</td>
</tr>
<tr>
<td>75 w (450 kgm)</td>
<td>100 w (600 kgm)</td>
<td>150 w (900 kgm)</td>
<td>150 w (900 kgm)</td>
</tr>
<tr>
<td>100 w (600 kgm)</td>
<td>150 w (900 kgm)</td>
<td>200 w (1200 kgm)</td>
<td>200 w (1200 kgm)</td>
</tr>
</tbody>
</table>

Additional Stages: increase by 25 w increase by 50w increase by 50w

Heart rate is measured in the last 15 seconds of the 2nd and 3rd minutes. If steady state is reached (a variance of less than 6 beats per minute between these two heart rates), the workload is advanced. If steady state is not reached, an additional minute is added to the stage until steady state is reached.

Blood pressure will be measured in the last minute of every stage.

The test will be terminated when 85% of the maximal age-predicted heart rate is reached, or the subject experiences any of the general indications for stopping an exercise test in low risk adults (3).

Maximum VO2 will be estimated by graphing the last two heart rates and extrapolating the line to the age-predicted maximal heart rate. It will also be calculated using the multistage model equation.
APPENDIX B

PRE-TEST INSTRUCTIONS

1.) Wear comfortable, loose fitting clothing that will allow freedom of movement.

2.) Drink plenty of fluids during the 24-hour period before the testing to ensure hydration.

3.) For at least 3 hours prior to the test, avoid food, tobacco, alcohol, and caffeine.

4.) Avoid exercising or participating in strenuous physical activity the day of the test.

5.) Get adequate sleep (6-8 hours) the night before the test.
APPENDIX C

EXERCISE HABITS

1. Do you exercise vigorously on a regular basis? Yes No

2. What activities do you engage in on a regular basis?

3. If you walk, run, or jog, what is the average number of miles you cover each workout? _____ miles

4. How many minutes on average is each of your exercise workouts? _____ minutes

5. How many workouts a week do you participate in on the average? _____ workouts
APPENDIX D

FITNESS EVALUATION

Subject ID#: _______________________

Resting Heart Rate: ______________________  Normal = 60-80.

Resting Blood Pressure: ______________________  Normal = below 140/90.

Weight: ______________________  Body Fat: ______________________

Standards for body fat percentage:

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>At risk</td>
<td>&lt;5%</td>
<td>&lt;8%</td>
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<tr>
<td>Less than average</td>
<td>6-14%</td>
<td>9-22%</td>
</tr>
<tr>
<td>Average</td>
<td>15%</td>
<td>23%</td>
</tr>
<tr>
<td>More than average</td>
<td>16-24%</td>
<td>24-31%</td>
</tr>
<tr>
<td>At risk</td>
<td>&gt;25%</td>
<td>&gt;32%</td>
</tr>
</tbody>
</table>

Tips for reducing body fat:
--Select an activity (walking, swimming, biking) that can be performed at a low to moderate intensity for a long duration (30 minutes or more). Daily exercise increases caloric expenditure and ensures that weight loss is due to a decrease in fat tissue, not muscle. Resistance training such as weight lifting is also effective.
--Limit caloric intake, especially refined sugars and saturated fats. **Eat a well balanced diet!** Carbohydrate restriction causes a slowdown of fat metabolism, so fats are stored more than used, and the energy demands of the body are met by the breakdown of muscle. These types of diets may seem effective, but they cause rapid dehydration so the "weight" loss is due to a loss of water, not fat.
High protein diets place additional stress on the kidneys because they must work harder to excrete the excess nitrogen in protein. Large quantities of water must be consumed to prevent dehydration.
High fat diets cause high cholesterol and triglyceride levels.
--Skipping meals results in the body increasing the amount of fat-depositing enzymes, so more fat is stored and metabolism slows down. Nutritionists advise eating 3-6 small meals per day.

--Remember, spot reduction is no more effective than all-over body exercises. A sit-up program will strengthen the abs but won’t reduce abdominal body fat better than other exercises that target other areas. Total body exercise is best for the reduction of body fat, and the changes will occur to all areas.

VO2 maximum (aerobic capacity): __________ml/kg/min**

Standards, age 20-29:

<table>
<thead>
<tr>
<th></th>
<th><strong>Male</strong></th>
<th><strong>Female</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
<td>49+</td>
<td>42+</td>
</tr>
<tr>
<td>Excellent</td>
<td>45-48</td>
<td>38-41</td>
</tr>
<tr>
<td>Good</td>
<td>42-44</td>
<td>35-37</td>
</tr>
<tr>
<td>Fair</td>
<td>38-41</td>
<td>32-34</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;37</td>
<td>&lt;31</td>
</tr>
</tbody>
</table>

**The bicycle test may underestimate your true VO2 maximum by up to 15%, especially if you stopped due to leg pain or leg fatigue.

**Tips for improving your aerobic fitness level:**
--Select rhythmical activities that can be maintained continuously and that involve large muscle groups. Some examples are walking, jogging, aerobics, in-line skating, swimming, basketball, or circuit training.
--The intensity should be at least moderate, depending on the person’s fitness level.
--These activities should be done 3-5 days per week, for 20-60 continuous minutes.


The purpose of this study is to better understand the methods of submaximal exercise testing. A comparison will be made between an estimated VO2 maximum from the beginning stages and comparing that to the maximum VO2 that was measured.

Thank you for participating in my research project!!
--Julie Valentour
APPENDIX E

STATEMENT OF PURPOSE

The purpose of this study is to find out, by using the ACSM submaximal cycle ergometer test, if the 85% heart rate maximum termination provides a more accurate estimate of aerobic capacity than the 70% heart rate maximum termination.

SIGNIFICANCE OF THE STUDY

The significance of my study is that it provides insight into the methods of assessing VO2 maximums through submaximal testing procedures. This may validate the action of the American College of Sports Medicine for changing the guidelines of submaximal testing. It may also show that, for less well-trained subjects, it is not necessarily better to push them to 85% of their age-predicted maximal heart rate to get an estimate of their aerobic capacity. This may make the tests shorter, easier to perform, and less physically demanding for the subject.

RESEARCH QUESTIONS

1. For the ACSM submaximal cycle ergometer test, is it better to extend to 85% heart rate maximum, or to end it at 70%?

2. How well do each of these tests correlate to the actual measured VO2 maximum?

   If terminating at 85% is better, is it significantly better?
APPENDIX F
LIMITATIONS

LIMITATIONS

1. Assumptions of submaximal testing: Maximum heart rate is the same for everyone at a given age, steady state heart rate is attained for each workload, a linear relationship exists between heart rate and workload, and VO2 at a given workload is the same for everyone.

2. Due to localized leg fatigue, the subjects may not have been able to reach their true potential for VO2 maximum.

3. The sample was not randomized, a convenient sample was used.

DELIMITATIONS

1. The subjects were college undergraduates participating in physical activity classes, in an age range of 18-25.

2. The beginning and intermediate volleyball classes were chosen of all the physical activity classes.

3. All of the students were attending classes at the same university and most were from the same region of the country.

4. Only the cycle ergometer test was used to determine aerobic capacity.
ASSUMPTIONS

1. Assumptions of submaximal testing: Maximum heart rate is the same for everyone at a given age, steady state heart rate is attained for each workload, a linear relationship exists between heart rate and workload, and VO2 at a given workload is the same for everyone.

2. Maximal efforts were assumed to be given by all subjects if two or more of the criteria were met.

3. The sample represents the students of the volleyball classes at the university.
APPENDIX G
DEFINITIONS

Ateriovenous oxygen difference-the difference between the oxygen content of arterial blood and that of venous blood.

Coronary artery disease-a progressive atherosclerotic narrowing of the coronary arteries with a reduction in the blood and oxygen supply to the heart muscle.

Ergometer-an apparatus or device such as a treadmill, a stationary bicycle, or steps, used for measuring the physiologic responses to exercise.

Maximal exercise testing-performing a multistaged, graded exercise test to determine an individual’s VO₂ maximum. The individual exercises at gradually increasing workloads, usually performed for three minutes at each stage. The maximum aerobic capacity (VO₂ max) is when the oxygen uptake plateaus, which means that it does not increase by more than 150 ml/min^{-1} with an increase in workload.

Maximal Heart Rate-the maximal number of times a heart can beat per minute during maximal physical exercise.

Metabolic equivalent unit (MET)-a resting metabolic unit, the equivalent of 1.2 kcal/min or 3.5 to 4.0 ml/kg/min^{-1}. One MET equals the amount of energy expended at rest.
Open-circuit spirometry—the analysis of two factors: the volume of air breathed during a certain time period and the composition of the expired air.

Rating of Perceived Exertion—a valid and reliable tool to measure exercise intensity based on a scale for the participant to quantify their perceived level of physical exertion.

Respiratory Exchange Ratio—the exchange of oxygen and carbon dioxide in the lungs during exercise, when the ratio no longer represents the oxidation of specific foods in the cells. The buffering of lactic acid produced during exercise creates carbonic acid, which can be broken down into its component parts, carbon dioxide and water. This release of extra carbon dioxide through the lungs causes the ratio to go above 1.0.

Submaximal exercise testing—testing similar to maximal VO2 testing, but terminating at some predetermined heart rate intensity. These are analyzed to measure oxygen uptake during physical activity and to infer the energy expenditure used to perform the activity.

VO2 maximum—the rate of oxygen uptake during maximal aerobic exercise, reflecting the capacity of the heart, lungs, and blood to transport oxygen to the working muscles, and the utilization of oxygen by the muscles during exercise.
APPENDIX H

CONSENT FORM

Georgia Southern University
Department of Health and Kinesiology

“CONSENT TO PARTICIPATE IN A RESEARCH PROJECT” FORM

I understand that I will be participating in a project titled Determining Test Termination Percentage of Heart Rate Maximum When Using the Submaximal ACSM Cycle Ergometer Test, conducted by Julie Valentour (489-3340) and Garth Spendiff (871-1979).

Name of participant: __________________________ Date: __________________________

I will be asked to complete information regarding my medical history and lifestyle activities. I will be as accurate and honest as possible with all of the information required. I also understand that in order to assess my fitness level, I voluntarily consent to engage in the following tests:

A. A resting blood pressure test.

B. A resting heart rate evaluation.

C. Weight measurement.

D. A body composition test. The three site skinfold test will be used to determine the amount of body fat versus the amount of lean body mass.

E. A maximal graded exercise test. The test that will be used is the American College of Sports Medicine bike test. Participants will pedal at a rate of 60 RPM while the resistance increases incrementally every 3 minutes. I understand that I will breathe through a mouthpiece thus allowing the direct collection of expired gases for analysis while exercising. This will continue until the participant reaches his or her maximum ability and voluntarily requests to stop. If I experience unusual discomfort I may stop the test at any time.

Risks and Discomforts

During the bike test, certain changes may occur. These changes include abnormal blood pressure responses, fainting, irregularities in heart rate, and heart attack.
Every effort will be made to minimize these occurrences. Emergency equipment and trained personnel will be present to deal with these situations if they occur.

There is a slight possibility of pulling or straining a muscle during the bike test. In addition, you may experience muscle soreness 24 to 48 hours after testing. These risks can be minimized by performing warm-up exercises prior to taking the tests. If muscle soreness occurs, appropriate stretching exercises to relieve this soreness will be demonstrated.

**Expected Benefits From Testing**

These tests allow me to assess your physical working capacity and to appraise your physical fitness status. These results will be used for the thesis work I will explain to you.

**Confidentiality**

Records are kept strictly confidential and no names will be used in the thesis. I understand that all data concerning myself will be kept confidential and available only upon my written request to Julia Valentour. I further understand that in the event of publication, no association will be made between the reported data and myself.

**Inquiries**

Questions about the procedures used in the fitness testing are encouraged. If you have any questions or need additional information, please call Julia Valentour at (912) 489-3340. If you have any questions or concerns about your rights as a research participant in this study, you may also contact Dr. Matthew Williamson, Chair of the Departmental IRB, (912) 681-1820, or the IRB Coordinator at the Office of Research Services and Sponsored Programs at (912) 681-5465.

**Freedom of Consent**

I understand that I may terminate participation in this study at anytime without prejudice to future care or any possible reimbursement of expenses, compensation, employment status, or course grade except provided herein, and that owing to the scientific nature of the study, I have read this form carefully and I fully understand the test procedures that I will perform and the risks and discomforts. Knowing these risks and having had the opportunity to ask questions that have been answered to my satisfaction, I consent to participate in these tests.

Participant’s Name (print):

Participant’s Signature:

Date:
APPENDIX I

HEALTH HISTORY

SUBJECT NUMBER: ______________________ DATE: ______________________

To help determine your health status, please read the following questions carefully and answer each one honestly. All information will be kept confidential.

PLEASE CHECK YES or NO

♦ Known Disease/Risk

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<tr>
<th>QUESTION</th>
<th>YES</th>
<th>NO</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a heart condition?</td>
<td></td>
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<tr>
<td>Do you feel pain in your chest brought on by physical activity?</td>
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<tr>
<td>In the past month, have you had any chest pain?</td>
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<tr>
<td>Have you ever experienced a stroke?</td>
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<tr>
<td>Do you have epilepsy?</td>
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<tr>
<td>Do you ever lose consciousness or control of your balance due to chronic dizziness?</td>
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<tr>
<td>Do you have emphysema?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Do you have chronic bronchitis or other pulmonary condition?</td>
<td></td>
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<tr>
<td>Are you pregnant?</td>
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</tbody>
</table>

♦ Risk Factors

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>YES</th>
<th>NO</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have any muscular or joint problems? If yes, where?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Are you currently being treated for a bone or joint problem that restricts you from engaging in physical activity?</td>
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<td></td>
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<tr>
<td>Has a physician ever told you or are you aware that you have high blood pressure?</td>
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<tr>
<td>Has anyone in your immediate family (parents/brothers/sisters) had a heart attack, stroke, or cardiovascular disease before age 55?</td>
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<td></td>
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<tr>
<td>Has a physician ever told you or are you aware that you have a high cholesterol level?</td>
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<tr>
<td>Do you have diabetes?</td>
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<tr>
<td>Do you currently smoke?</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Are you a male over 45 years of age or female over 55 years of age?</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>QUESTION</td>
<td>YES</td>
<td>NO</td>
<td>COMMENT</td>
</tr>
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<td>------------------------------------------------------------------------</td>
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<tr>
<td>Have you ever had a stress test? If yes, when, and what was the result?</td>
<td></td>
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<tr>
<td>Are you currently taking any medication? Please list the medication and its purpose.</td>
<td></td>
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Cleared to exercise_____  Not cleared to exercise_____

Reason__________________________________________

PI Signature____________________________________
APPENDIX J

REVIEW OF LITERATURE

The purpose of this paper is to determine the accuracy of the submaximal exercise test termination criteria of 85% maximal heart rate as compared to 70%, the two end points used with the ACSM submaximal cycle ergometer test. The termination criteria for submaximal testing in the 4th Edition of ACSM’s Guidelines for Exercise Testing and Prescription (1991) called for the end point of submaximal testing to be 65-70% of maximal heart rate. Although it was not tested for validity, the termination criterion was raised in the 5th Edition of the Guidelines book to 85% (ACSM, 1995). The purpose of this research project was to determine which percentage of maximal heart rate test termination has a stronger correlation to maximal cycle ergometer testing.

It is estimated that one in every five people in the United States has some form of cardiovascular disease (CVD) including hypertension, coronary heart disease, congestive heart failure, and/or stroke (ACSM, 2000). Coronary heart disease (CHD), one form of CVD, causes more deaths each year in the U.S. than any other disease (Heyward, 1998). Its main cause is atherosclerosis, a progressive and degenerative disorder that involves the buildup of fibrous plaque and fat deposits beneath the inner lining of the coronary arteries. This results in a decreased blood flow to the heart and a lack of oxygen and nutrients reaching the heart muscle, which causes chest pain, called angina pectoris (Heyward, 1998). Shortness of breath,
nausea, sweating, or pain that radiates down the neck and jaw or to the left arm may also be symptoms of cardiac ischemia (ACSM, 1991). One third of all deaths in the U.S. for those aged 35-75 are from CHD in the form of either cardiac arrest or myocardial infarction (Skinner, 1993). Myocardial infarction occurs when a blood clot seals off the artery passageway, and this lack of blood flow causes ischemia, or tissue death (Heyward, 1998).

Some of the uncontrollable factors that increase the risk of CVD are age, heredity, and sex. There are also controllable factors that contribute to increased risk such as: hypercholesterolemia, hypertension, smoking, diabetes mellitus, and physical inactivity (Heyward, 1998).

Pate et al. (1995) defines physical activity as “any bodily movement produced by skeletal muscles that results in energy expenditure” (p.402). Physical activity is not the same as physical fitness. Physical activity is a behavior that can result in physical fitness, which is an attribute (Pescatello, 2001). Exercise is a type of physical activity that involves planned, structured, repetitive movement for the purpose of maintaining or enhancing physical fitness (Pescatello, 2001). Physical activity can also result in an increased state of cardiorespiratory fitness, which is the ability to sustain dynamic exercise using large muscle groups at a moderate to high intensity (ACSM, 1995). Cardiorespiratory fitness is inversely related to the relative risk of developing cardiovascular disease (Heyward, 1998). Therefore, promoting physical activity is a major public health issue, as illustrated by the 1996 U.S. Surgeon General’s report on
physical activity and health. In the U.S., approximately 12% of all deaths are attributed to physical inactivity (Pate, 1995).

The Benefits of Physical Activity

Physical activity can lead to an improvement of cardiorespiratory fitness (Pate, 1995), which is essential to health for two reasons. First, people with poor cardiorespiratory fitness levels have shown a higher increased risk of premature death from cardiovascular disease as well as from all other causes (Blair, 1995). Secondly, physical activity has been shown to reduce the relative risk of mortality of all causes. Physical activity is shown to decrease the risk of chronic illnesses such as coronary heart disease (Blair, 1995). Physical activity acts on the autonomic nervous system, and at a given submaximal work rate, it decreases both blood pressure and the oxygen demands of the heart (Franklin, 2000). Benefits are seen in skeletal, muscular, and nervous systems, and include a reduction in both systolic and diastolic blood pressure by about 10 mmHg in hypertensive adults (Heyward, 1998). Some researchers have also found that physical activity can also increase high-density lipoprotein cholesterol (HDL) levels, and decrease triglycerides, as well as decrease total cholesterol and low-density lipoproteins (LDL) levels for those with previously high levels (Heyward, 1998). Also, physically active persons will increase their chance of survival after a myocardial infarction (O’Connor, 1989).

Other benefits include the reduction of body fat and body weight. This, combined with the increased sensitivity to insulin, can reduce the risk of developing non-insulin dependent diabetes mellitus (Heyward, 1998). After a bout of dynamic
exercise, the insulin sensitivity in the muscles may last for up to 48 hours and glucose uptake into the muscle and liver cells is enhanced. This may significantly reduce the amount of insulin necessary for individuals who receive this type of therapy (Skinner, 1993). The recommended amount of physical activity is 30 minutes or more, on most, if not all, days of the week (Pate, 1995). It should involve large muscle groups and burn approximately 200 calories per day. Moderate intensity exercise is recommended, and the 30 minutes may be accumulated over the course of the day (Pate, 1995).

What is VO₂ Max?

Most of the body’s systems rely on negative feedback to maintain homeostasis, or stability in the normal body states. At the onset of exercise, this homeostasis is upset by changes that occur in the physical and chemical environments of the cells. As the body temperature rises, lactate accumulation causes an increase in the acidity of the blood, the oxygen concentration decreases, and the carbon dioxide rises (Lamb, 1978). Receptor cells, located in the base of the brain, the aorta and carotid arteries and in nerve endings in the joints and muscles, sense the changes occurring in the body and signal organs that control respiration to increase the rate of breathing. This serves to decrease the carbon dioxide, increase oxygen, and to decrease the acidity in the blood by increasing respiration (Lamb, 1978). Therefore, the lungs begin to take in more oxygen and the body begins to use more, increasing for each increase in intensity level, and then leveling off after a few minutes (Fletcher, 1995). This is known as the “steady state” where the oxygen uptake, as well as the heart
rate, cardiac output, blood pressure, and pulmonary function become stable. This occurs at each level of exercise intensity. \( \text{VO}_2 \text{max} \) is directly related to the ability of the lungs, heart and circulatory system to transport oxygen, and the ability of the body tissues to use oxygen (Baechle, 1994). Maximum oxygen uptake represents the oxygen used in cellular metabolism, and is related to the ability of the heart, lungs, and blood to transport oxygen to the working muscles to be used during exercise. An increase in a person’s aerobic capacity from training occurs due to the increased oxygen requirements of the body and then subsequently a larger amount of carbon dioxide to eliminate through alveolar respiration. Training increases the amount of oxygen extracted from the blood by the muscles, resulting in a greater arteriovenous difference (the amount of oxygen in the arteries versus that in the veins), especially in the muscles used during the exercise (Baechle, 1994).

\( \text{VO}_2 \text{max} \) may be represented mathematically by the maximum arteriovenous oxygen (a-v \( \text{O}_2 \)) difference multiplied by the maximum cardiac output (Baechle, 1994). Heart rate is directly associated to \( \text{VO}_2 \text{max} \) because cardiac output, the amount of blood pumped per minute by the left ventricle, is the product of stroke volume multiplied by heart rate (Baechle, 1994). Stroke volume is the difference between the end diastolic volume of the heart (the amount of blood that collects in a ventricle during relaxation) and the end systolic volume (the amount of blood in a ventricle after contraction) (Marieb, 1998). Stroke volume can also be referred to as the amount of blood pumped per beat, and it continues to increase during a bout of exercise until the participant reaches about 40-60% of their \( \text{VO}_2 \text{max} \). However,
heart rate, or the number of beats per minute, continues to increase linearly with increased \( VO_2 \). Therefore, the increases in cardiac output after the participant reaches about 40-60\% of their \( VO_2 \) max are due to increases in heart rate. A higher maximum cardiac output equals a higher maximum \( VO_2 \) (Foss, 1998). The major result of coronary artery disease is a decreased cardiac output, which results in a decline in exercise capacity (Fletcher, 1995).

\( VO_2 \) max can be formulated by rearranging the Fick equation. The Fick equation shows that \( VO_2 \) is equal to the HR multiplied by SV multiplied by the arteriovenous difference of oxygen in ml O\(_2\) per deciliter of blood \([aO_2] - [vO_2]\) (Franklin, 1995).

\[
VO_2 = HR \times SV \times (CaO_2 - CvO_2)
\]

Exercise can increase a person's \( VO_2 \) max by causing increases in cardiac output. This is not due to an increase in maximal heart rate, which is not commonly affected after training, so the increases seen in \( VO_2 \) max are the result of an increase in stroke volume (Fletcher, 1995). Aerobic training, or sustained dynamic exercise using large muscle groups, also causes a greater difference in the extraction of arteriovenous oxygen due to the greater capacity to deliver oxygen to the cardiovascular system and use by the muscles (Fletcher, 1995).

The units to express \( VO_2 \) max are in L/min\(^1\) or ml/min\(^1\). This is known as the absolute value of \( VO_2 \) max and is used primarily for non-weight bearing activities such as arm or leg cycle ergometry, as compared to weight bearing activities such as walking, running, and stair climbing (Heyward, 1998). \( VO_2 \) max is strongly related to fitness level (Baechle, 1994).
Because VO$_2$ max is directly proportional to body size, men typically have a higher absolute VO$_2$ max than women (Heyward, 1998). Genetic differences, found in total body energy output and caloric expenditure, are also a major contributing factor to VO$_2$ max differences between individuals (Franklin, 1995). Because humans are dynamic, it is extremely difficult to discover one or two major factors that contribute to VO$_2$ max when there may be a complex pattern. Each individual’s level of motivation is speculated to be a factor, but this cannot be quantifiably measured (Katch, 1982).

To compare the differences in VO$_2$ max among individuals of various body sizes, relative VO$_2$ max is used. Relative VO$_2$ max is expressed in relation to body weight and the units are ml/kg/min$^{-1}$. The expression of VO$_2$ in ml/kg/min$^{-1}$ or METs is considered to be the best indicator of cardiopulmonary fitness or physical work capacity (Franklin, 1995). The VO$_2$ at rest for an average adult is estimated to be 3.5 ml of oxygen per kilogram of body weight per minute, or 3.5 ml/kg/min$^{-1}$ (Foss, 1998). This is equivalent to one MET. The amount of METs a person can tolerate during exercise depends on their conditioning (Baechle, 1994). An exercise prescription for an active, healthy person should include exercise at an intensity equal to about 6 to 7 METs (Heyward, 1998).

Peak values for VO$_2$ max are reached between the ages of 15-30, and decrease progressively after age 30 (Fletcher, 1995). Sixty-year-old men have about 75% of the VO$_2$ max that they did at age 20. An active lifestyle can slow down these
physiological changes that occur (less than 5% loss per decade as compared to 9% for sedentary adults) (Fletcher, 1995).

**Is VO\(_2\) max the best measurement of cardiorespiratory fitness?**

VO\(_2\) maximum is measured by testing the person’s maximum aerobic capacity, or a person's ability to perform aerobic activity. The VO\(_2\) maximum measures functional limitations of the cardiovascular system, the ability of the oxygen to be utilized by the body (Heyward, 1998). It is believed to be the most widely recognized index of exercise capacity (Franklin, 1995).

Maximum aerobic capacity, or VO\(_2\) max, is a better predictor of aerobic performance in older athletes than VO\(_2\) at lactate threshold, a previously used method of determining aerobic capacity (Wiswell, 2000). Lactate threshold is the time during aerobic exercise when the concentration of blood lactate begins to rise exponentially. Wiswell et al (2000), in a study of older runners found that the loss of Type II (fast twitch) fibers lowers the accumulation of lactate during exercise because the fast twitch fibers have a higher fatigue rate and produce more lactic acid in the body (Baechle, 1994). This loss of fast twitch fibers, a natural occurrence in the aging process, causes a lactate threshold to occur at a higher VO\(_2\) in older runners than in younger runners (Wiswell, 2000). Therefore, it may be beneficial to use VO\(_2\) max instead of VO\(_2\) at lactate threshold to assess an individual's fitness level if age is a factor (Wiswell, 2000).
Why Do Exercise Testing?

Oxygen consumption during exhaustive work is the best for predicting work capacity and is the most objective for assessing cardiorespiratory fitness (Cooper, 1968). The oxygen use of muscles is related to the size of the muscle mass involved and the ability of the muscle to perform work. Thus, aerobic exercises involving a greater amount of muscle work results in a higher amount of oxygen use. A person’s aerobic conditioning is represented by VO$_2$ max and, therefore, it is an index of total body fitness, or degree of physical conditioning (Baechle, 1994). Exercise tests that determine VO$_2$ max can be used to classify the cardiorespiratory fitness level of an individual into grades of superior, excellent, good, fair, and poor. This information can help with setting goals and making accurate exercise prescriptions. These tests can also provide objective data to follow the progress of a training program over time (Heyward, 1998). These tests need to be strenuous in nature because the less exertion required, the less apparent are the differences between the fit and the unfit (Cooper, 1968).

Exercise testing is done because the stress of exercise can show more information about the heart muscle than can be seen at rest. Franklin (1995) gives several reasons for exercise testing. The first is to help diagnose the presence of cardiovascular disease in individuals, i.e., whether they are symptomatic or asymptomatic. Ischemia is a decrease in blood flow to an organ usually due to a blocked or constricted artery (American Heart Association, 1995). Ischemia is diagnosed in individuals whose electocardiograms (ECGs) show abnormalities in the
ST segment (the beginning of ventricular repolarization) or the T wave (the rapid phase of ventricular repolarization (ACSM, 1991). Another reason for exercise testing is to assess the improvements in an individual’s functional capacity due to such interventions as coronary artery bypass surgery, angioplasty, cardiac medications, or a fitness program. Also, the exercise test can aid in determining the capacity for doing physical work, determine the safety of exercise, and can help with prescribing exercise programs (Franklin, 1995).

**How to Measure VO\textsubscript{2} Max**

Direct analysis of VO\textsubscript{2} max is the preferred method for research or clinical testing laboratories. This involves a form of progressive intensity exercise using an ergometer (such as the bike or treadmill) and the collection of expired oxygen and carbon dioxide and the use of equipment that can calculate the amount of oxygen directly used by the body. This direct measurement of gas exchange is the most accurate method for measurement; but it requires specialized equipment, such as a bicycle ergometer or treadmill, an electrocardiogram monitoring system with a medical crash cart, and a defibrillator. These units can be costly, ranging from a total of between $15,000 to $40,000 (Darrow, 1999). Also, direct analysis of VO\textsubscript{2} max requires calibration of the equipment which is time consuming (ACSM, 2000). Specially trained test administrators are also required, such as someone trained in Advanced Cardiac Life Support (Darrow, 1999).

VO\textsubscript{2} max testing is a graded or multi-staged procedure, which means that the workloads at each level should be increasing in intensity (Heyward, 1998).
Attainment of a VO$_2$ max occurs when the oxygen uptake reaches a plateau (does not increase by more than 150 ml/min with a further increase in workload) (Heyward, 1998). However, some subjects cannot achieve this maximum intensity due to fatigue, leg pains, or lack of motivation (Noonan, 2000). Several criteria are used to indicate a successful VO$_2$ max test. One gauge is the failure of the heart rate to increase with increases in exercise intensity due to the participant reaching their maximal heart rate. An accumulation of more than 8 mM/L of venous lactate concentration is also an indicator. The respiratory exchange ratio (RER) is the ratio of the exchange of oxygen to carbon dioxide in the lungs. The measurement of RER during exercise testing exhibits the buffering action of the lactic acid produced in the body. This buffering produces the weaker carbonic acid, which can be broken down into carbon dioxide and water. The carbon dioxide exits through the lungs and the RER increases above 1.0. An RER greater than 1.15 is used as an indication of a maximal effort (McArdle, 1999). Also, maximal effort is determined if the participant gives a rating of perceived exertion of greater than 17 on the original 6-20 Borg scale (Heyward, 1998). This scale is used to enable participants to subjectively rate the level of exertion during exercise, and is closely related to both heart rate and VO$_2$ (Heyward, 1998).

**Maximal testing**

The maximal test requires participants to exercise until they reach a point of volitional fatigue. It still can be used to diagnose coronary artery disease in asymptomatic individuals, but it is not very practical for most health and fitness
practitioners (ACSM, 1995). The American College of Sports Medicine recommends maximal testing for: apparently healthy men over 40 and women over 50 who desire to begin a vigorous exercise program (above 60% VO\textsubscript{2} max), men and women who are asymptomatic for cardiovascular disease but with two or more major risk factors (high cholesterol, smoking, hypertension, sedentary) who wish to take up vigorous exercise, or any individual with symptoms of cardiac, pulmonary, or metabolic disease (Franklin, 1995).

**Submaximal testing**

Because maximal testing using direct analysis of gases is not always necessary or feasible, other tests have been developed that estimate VO\textsubscript{2} max, called "submaximal" tests to allow the testing to be performed in field settings. This eliminates the need for expensive equipment, recurrent calibration, and technical expertise (Franklin, 1995). Results from these submaximal tests are used to calculate VO\textsubscript{2} max based on other physiologic responses such as heart rate and work load or time to voluntary fatigue (ACSM, 1995), and predict VO\textsubscript{2} max with an estimated standard of error of about 10% (Shephard, 1979).

However, there are some populations whose VO\textsubscript{2} max may not be able to be estimated from a submaximal test. The cardiac patient’s VO\textsubscript{2} max may be overestimated when predicted by an indirect method of testing (Franklin, 1995). There are several reasons for this. One is that the nomograms published for the comparison of treadmill VO\textsubscript{2} max tests were generally created using healthy young adults not using the handrails. Dysfunction of the left ventricle due to cardiac
ischemia may cause a slower oxygen uptake. Also, beta-adrenergic blocking cardiac medications may slow heart rate and therefore result in lower physiologic responses to a given work rate (Franklin, 1995). In these cases, it is necessary to measure VO₂ max using maximal tests.

Submaximal tests are terminated below the maximal effort as determined by heart rate. The heart rate cutoff can be strenuous or near maximal for those of very low fitness level, while for others who are trained, it is very minimal (Fletcher, 1995). The termination point is set at a predetermined intensity of their age predicted maximal heart rate, estimated by 220 minus the subject's age (Heyward, 1998). Maximum heart rate is the highest rate of sinus node activity recorded at the end stages of an exercise test (Whaley, 1992). Errors with this type of assumption include the accuracy of prediction of this maximal heart rate due to individual differences. The general standard of error of this prediction is +/- 15 beats per minute, which can be a problem with submaximal testing. A study by Whaley et. al (1992) found that the formula tended to under-predict the maximum heart rate of those who were older, had a higher resting heart rate, weighed less, and did not smoke. For those who were younger, heavier, smokers with a lower resting heart rate, the age-predicted heart rate maximum formula tended to over-predict their true maximum (Whaley, 1992). Despite the drawbacks of using this formula, it has become accepted for use in both clinical and fitness settings (Whaley, 1992).

Submaximal tests were developed for health and fitness practitioners to determine cardiorespiratory fitness for their clients. Submaximal testing aims to measure a
submaximal VO₂ at each given stage of work due to the subject's heart rate responses at each stage. There is a relatively linear increase in heart rate equaling 10 +/- 2 beats per MET for sedentary individuals (Franklin, 1995). Due to the linear relationship between heart rate and VO₂, it is possible to estimate VO₂ from a heart rate at a given intensity (Simmons, 2000).

By using a treadmill, a cycle ergometer, or a bench for stepping, procedures for estimating VO₂ can be performed. Timed runs for distance or distance covered in a specified time have also been methods to predict VO₂ maximum. For these, the heart rate response (the increase in heart rate due to increased workload) is sometimes not utilized. Outside factors such as the environment, motivation level, the ability to pace, and running efficiency can have an effect (Hartung, 1993). For example, a very hot climate or low motivation of an individual will reflect a lower VO₂ max. These types of tests can be performed in a variety of field settings as well as in a laboratory. Due to a wide variety of tests available, the appropriate test should be selected based on the ability to produce a sufficient level of exercise stress without creating physiologic or biomechanical injury (Noonan, 2000). Age, weight, mobility, nutritional status, cognitive status, and primary and secondary pathologies may be factors for test selection (Noonan, 2000).

Heart rate and submaximal VO₂ need to be measured during at least two intensity levels of exercise so they can be plotted as a linear relationship on a graph. These can be plotted with exercise intensity in watts, METS, or kgm/min on the y-axis and heart rate in beats per minute on the x-axis (see Figure 1). VO₂ max is then
determined from the workload found on the graph that corresponds with the extrapolation to the maximal heart rate, or it can be calculated using the multi-stage formula (ACSM, 1995).

Submax tests provide a “reasonable estimate” of cardiorespiratory fitness levels. They are not as sensitive for diagnosing coronary heart disease but are less expensive, take less time, and are less risky (Heyward, 1998). “Submaximal exercise testing, though not as precise as maximal exercise testing, can still provide a reasonably accurate reflection of an individual’s fitness without the cost, risk, time, and effort on the part of the subject” (ACSM 1995, p.66).

Assumptions Made by Submaximal Exercise Tests

To predict VO$_2$ max, four assumptions must be made for using submaximal tests. The first is that a steady state heart rate is achieved at each workload of incremental exercise. Second, a linear relationship also is assumed to exist between each workload and its corresponding heart rate, as discussed earlier. Third, the maximal heart rate using the age-predicted formula (220 minus age) gives a standard maximal heart rate for all persons of a given age. Lastly, the VO$_2$ at each given workload is assumed to be the same for all individuals (ACSM, 2000).

Selection of a Test (Maximal or Submaximal)

Test selection is determined by several factors including the client’s age and the presence of disease, the reason for administering the test, if it is for fitness or clinical purposes, and the availability of the appropriate equipment and trained personnel (Heyward, 1998).
**Safety of Performing Exercise Testing**

Before exercise testing, a screening and evaluation process should be administered. This can help screen those who may be at risk for exercise complications such as those with heart conditions or joint problems (ACSM, 1995). This includes obtaining informed consent, medical history forms, and a thorough fitness evaluation with exercise testing. Exercise tests are used for determining cardiac functioning as well as fitness testing. Because exercise is a common stressor on the heart, it can reveal functional abnormalities that are not present at rest. According to the American Heart Association, the exercise test should not be called a “stress test” because exercise is only one of many stressors on the heart. There is a considerable trend toward the use of nonexercise stress tests (Fletcher, 1995).

Hemodynamic responses, such as blood pressure and heart rate, improve the predictive value of exercise testing. Systolic BP rises at about 10 +/- 2 mm/Hg per MET to a plateau around peak exercise (Franklin, 1995). This increased blood pressure is important to monitor for the minimization of complications during testing. The excessive rise of blood pressure (>260 mm Hg systolic or > 115 mm Hg diastolic) is an indication for terminating the test. A significant drop of systolic blood pressure (SBP) by 20 mm Hg or more or the failure of SBP to increase with an increased workload also requires terminating a test. Dizziness, severe fatigue, or the onset of angina-like symptoms are other signs to stop testing. Signs and symptoms of an infarct are important for the administrator to be aware of, such as radiating chest pain which may disguise itself as back, jaw, abdominal, or lower neck pain or
tightness. It is important to classify these symptoms on a scale of 1-4 (mild, moderate, moderately severe, and severe) and to terminate the test if the rating goes beyond a 2 (moderate) (Franklin, 1995).

**Test Administrators**

Testing should be done by trained personnel with medical assistance available in case a cardiac event occurs during the testing procedure. Proper equipment, such as defibrillators, medications, and personnel that are certified in cardiopulmonary resuscitation (CPR) should be available during the procedure (Noonan, 2000).

For a maximal test, the test administrator can be a nurse or exercise specialist if the subject is apparently healthy, under 40 years old, and has no chest pain symptoms or stable chest pain symptoms. If the subject is at increased risk or the test is being administered for diagnostic purposes, a physician should administer the test (Franklin, 1995). The health professional who administers such a test should be aware of indications and contraindications of exercise testing, test termination criteria, and test interpretation (Franklin, 1995).

**Modes of Exercise Testing**

Several modalities of both maximal and submaximal tests exist. Treadmill testing may be the most popular and used most often by clinicians for diagnostic purposes. Cycle and arm ergometry, which involves pedaling a stationary bicycle or arm ergometer, can also be used if non-weight-bearing activity is preferred or there are balance or orthopedic impairments. With the cycle test method, some subjects may be less intimidated because there is minimal movement of the torso and arms
(Franklin, 1995). Other benefits are the ease of taking blood pressure and ECG measurements, and the cycles are less expensive and can be transported easily if necessary (Franklin, 1995).

For cycle ergometer testing, lower extremity fatigue can be a limiting factor for performance. Because the physiological responses may be different for cycle ergometry, VO$_2$ max is typically 5 to 15% less than when measured on a treadmill (Franklin, 1995). Similarly, Glassford et.al (1965) found that direct treadmill tests produce higher VO$_2$ max tests by 8% than does direct cycle ergometry. Twenty four males aged 18-33 were given three direct tests to measure maximal oxygen uptake. Two were treadmill protocols and one was a maximal cycle ergometer test. The one indirect test was the Astrand-Ryhming bicycle nomogram. The findings were that the two maximal treadmill tests and the indirect bicycle test were highly correlated, but the maximal cycle test produced significantly smaller means for VO$_2$ max. This was due to extreme muscular fatigue produced by excess pedaling on the cycle ergometer (Glassford, 1965). According to Cooper, muscle development through training is necessary to reach maximal effort on a cycle ergometer (Cooper, 1968). Specific fatigue in a limited muscular area does not impact the cardiorespiratory system as well as the general, total body fatigue that occurs in treadmill testing (Glassford, 1965). Therefore, the nature of physical activity performed can affect the actual value of VO$_2$ max measured for an individual (Glassford, 1965).
**Treadmill Testing**

Because walking and running do not solely impact a specific muscular region, treadmill testing is likely to result in a higher VO$_2$ max assessment than cycle ergometry, which may elicit a VO$_2$ max 80-95% of the treadmill test (Franklin, 1995). Walking is also a more common stress on the body than cycling (Franklin, 1995). Treadmill protocols should generally last 15 minutes or less, and should involve stages at least two minutes long to ensure steady state values are reached. Speed and grade, or sometimes both (depending on the protocol used), are increased incrementally at the beginning of each new stage with the increase being equivalent to 1 MET. The Bruce protocol, possibly the most well known and widely used, is well established to provide safe progression of exercise and standard values for heart rate, blood pressure, and VO$_2$. However, the first stage requires a workload of 4-5 METs, above the ability of some lower level cardiac patients (Franklin, 1995). The test begins with the individual walking at 1.7 miles per hour (mph) at a 10% grade for three minutes. During the second stage, the speed is increased to 2.5 mph and the grade is increased by 2% for another three minutes. Each stage following requires the speed to increase by 0.8 or 0.9 and the grade to increase by an additional 2% until the subject reaches exhaustion. To allow this test to be performed by high risk and elderly persons, the Modified Bruce protocol was created. It is similar except for the first two stages, where the grade begins at 0% for stage one and is 5% for stage two (Heyward, 1998).
Sensitivity and Specificity

Sensitivity is a measurement of how accurately a test can classify those who have a certain disease. The sensitivity in the case of maximal and submaximal exercise testing is the ability of the tests to classify participants correctly for their level of cardiorespiratory fitness (Weller, 1992). Some factors that affect the sensitivity of maximal exercise testing are cardiac drugs such as digoxin that cause a reduction in heart rate, sex of the subject, left ventricular hypertrophy, and baseline ECG patterns. If a person is taking an androgenic beta-blocker, digoxin, or another medication that slows heart rate, the test may show that they are healthy when in fact they are not. The sex of the subject may also affect the results. In a study by Weller et. al (1992), a 20-year-old female with a VO₂ max of 40 ml/kg/min would be placed in the excellent category, while a male with the same value would be considered below average (Weller, 1992). This is due to the body size differences as discussed previously.

Sensitivity reflects the percentage of those who do not have the disease and who will have negative tests for it (Weller, 1992). The number of correctly classified subjects in the below average group is the rating of specificity for the study by Weller et. al (1992). The population tested affects both sensitivity and specificity. A test will have higher sensitivity if the population is more prone to have the disease. Overall, exercise stress testing has a sensitivity ranging from about 23 to 100 percent and a specificity of about 17 to 100 percent (Darrow, 1999).
Validity and Reliability

Two important concepts for exercise testing are validity and reliability. Criterion validity is the comparison of a measurement to a recognized criterion or standard and the degree to which they are similar. Two contexts in which this is used are concurrent and predictive validity. To achieve concurrent validity, a test will have a high correlation with one administered at the same time (Thomas, 1996). Maximal and submaximal tests can achieve concurrent validity. The ability to predict a value from a set of variables is called predictive validity. For predictive validity, a test will have a number of variables used in the prediction process, and a statistical method called multiple regression is often used to predict an outcome or criterion. Some non-exercise tests have been developed that use this regression technique to predict VO₂ max based on resting measurements (Heil, 1995).

In the Weller et. al study (1992), the predicted VO₂ max values calculated using a multiple regression equation developed by Jette et. al (1976). This was also the method used to determine the maximal VO₂ from the Canadian Aerobic Fitness Test in a study by Cox et. al (1992). Comparing the results to a “gold standard” such as the treadmill test with direct spirometry can validate submaximal tests. In the study by Cox et. al (1992), thirty subjects performed the Canadian Aerobic Fitness Test (a six minute step test), which was compared to a maximal treadmill test. The correlation was found to be high (.90), however, the large standard error may cause individuals to be classified incorrectly for their fitness level (Cox, 1992). Paired t
tests can also be used to compare the results of the two types of testing (direct or predictive) as used in the Weller study (1992).

Reliability, or consistency, is a very important part of validity. Reliability is the ability of a test to be repeated and the same results observed. This is established by three methods: stability, alternate forms, and internal consistency. The alternate forms method of determining reliability involves administering two different tests that measure the same material. The tests are usually given on separate occasions with some time elapsing in between. If the tests are highly correlated, reliability is shown. Internal consistency is measured in several ways. If a group of subjects are tested twice on the same day for the same variables, the tests should be highly correlated for internal consistency. A more common method of testing internal consistency is the use of a coefficient or Cronbach's alpha. This calculates the amount of variance of the parts of a test or for multiple trials of the same test.

External reliability refers to the degree that the study can be compared to the external environment and repeated in other situations. Internal reliability refers to the degree of agreement of the testers in the same study (Thomas, 1996).

**Conclusions**

Cardiovascular disease is the leading cause of death in the United States. Physical inactivity is one of the major risk factors (increasing the risk 1.9 times) of this disease. In order to live longer and healthier, Americans need to increase their levels of physical activity. One important aspect of this is to determine the safety and desired intensity of that exercise. Exercise testing is able to assist in exercise
prescription. It is also beneficial to determine the baseline fitness levels and to establish progress achieved by cardiorespiratory training. However, in order for exercise testing to be of value, it needs to accurately represent the VO$_2$ max of the individual subject. Validity needs to be determined, and submaximal VO$_2$ max testing should be strongly correlated to direct analysis of gases done during maximal testing.

In the Glassford (1965) study mentioned earlier, the correlations between the maximal treadmill tests and the submaximal cycle ergometer tests were measured. For the direct test using the Taylor, Buskirk, and Henschel treadmill protocol, the correlation coefficients were .72 for measurement in L/min$^{-1}$ and .63 for ml/kg/min$^{-1}$. For the Mitchell, Sproule, and Chapman treadmill protocol, the correlations were .78 when measured in L/min$^{-1}$ and .77 for ml/kg/min$^{-1}$. The relationship of the maximal Astrand bike protocol to the submaximal A-R nomogram was not as strong, with correlation coefficients at .65 in L/min$^{-1}$ and .63 for ml/kg/min$^{-1}$ (Glassford, 1965).

Cooper (1968) devised a 12-minute performance test, applied for use on 115 Air Force male officers and airmen. A maximal treadmill test with gas analysis was used for comparison, and the correlation coefficient was found to be highly significant at .897.

In the Fourth Edition of the American College of Sports Medicine’s Guidelines for Exercise Testing and Prescription (1991), the protocol for the ACSM’s submaximal bike test was to terminate the test at 65-70% of the age predicted maximal heart rate (ACSM, 1991). In the Fifth Edition, this is changed to 85% of the maximal heart rate
(ACSM, 1995). There is no documentation as to why these standards changed. A study by Greiwe et al, (1995) examined the validity and reliability of the 70% heart rate max test termination and found there to be as much as 25% overestimation of VO2 max (Greiwe, 1995). In this study, the examiners compared two trials of 70% heart rate max limits to a maximal cycle ergometry test. The standard error of estimate (SEE) values expressed as a percentage of the mean were also found to be high, suggesting that the ACSM bike test is not reliable nor valid as an accurate expression of VO2 max (Greiwe, 1995). One reason for this lack of accuracy may be due to the low termination criteria of 70% (Greiwe, 1995). However, they did not use a higher termination heart rate to check the improvement in accuracy. They did not attempt to compare the 70% to the 85% heart rate termination, so the correlation between the two submaximal tests is still unknown as well as the correlation between the 85% heart rate termination criteria and the maximal cycle test. It has been suggested that more studies need to be done to research this question (Heyward, 1998).
References


Institutional Review Board (IRB) Approval

To: Julia A. Valcieri
Health and Kinesiology

Cc: Garth Spendiff, Faculty Advisor
Health and Kinesiology

From: Mr. Neil Garrett
Coordinator, Research Oversight Committees (IACUC/IBC/IRB)

Date: March 9, 2001

Subject: Status of Application for Approval to Utilize Human Subjects in Research

After an expedited review of your proposed research project titled “Determining Test Termination Percentage of Heart Rate Maximum when Using the Submaximal ACSM Cycle Ergometer Test,” it appears that the research subjects are at minimal risk and appropriate safeguards are in place. I am, therefore, on behalf of the Institutional Review Board able to certify that adequate provisions have been planned to protect the rights of the human research subjects. This proposed research is approved through an expedited review procedure as authorized in the Federal Policy for the Protection of Human Subjects (45 CFR §46.110(7)), which states:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

However, this approval is conditional upon the following revisions and/or additions being completed prior to the collection of any data:

1. You will need to obtain letters of permission/support from each of the faculty members whose classes you will be using to solicit possible research participants. These letters should clearly indicate that he/she has granted you permission to utilize their classroom time to solicit for possible research participants. These letters must be obtained prior to the collection of any data. Please submit a copy of these letters to the IRB.

If you have any questions, comments, or concerns about these conditions of approval, please do not hesitate to contact the IRB Coordinator. Please send a copy of all revised and/or additional materials to the IRB Coordinator at the Office of Research Services and Sponsored Programs (PO Box 8005).

This IRB approval is in effect for one year from the date of this letter. If at the end of that time, there have been no changes to the exempted research protocol, you may request an extension of the approval period for an additional year. In the interim, please provide the IRB with any information concerning any significant adverse event, whether or not it is believed to be related to the study, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator prior to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, please notify the IRB Coordinator so that your file may be closed.
To: Julia A. Valentour  
Health and Kinesiology  

Cc: Garth Spediff, Faculty Advisor  
Health and Kinesiology  

From: Mr. Neil Garretson, Coordinator  
Research Oversight Committees (IACUC/IBC/IRB)  

Date: March 23, 2001  

Subject: Status of Conditional IRB Approval to Utilize Human Subjects in Research  

The Institutional Review Board (IRB) Committee has received your revised and/or additional application materials for the approved research titled, “Determining Test Termination Percentage of Heart Rate Maximum when Using the Submaximal ACSM Cycle Ergometer Test.” You have satisfactorily met the conditions of your Institutional Review Board (IRB) approval, as detailed in the March 9, 2001 approval letter.  

Please remember that this approval is in effect for one year (3/9/01 – 3/9/02) and if at the end of that time there have been no substantive changes to the approved methodology, you may request a one year extension of the approval period.  

Good luck with your research efforts, and if you have any questions, comments, or concerns about the status of your approval, please do not hesitate to contact me.
APPENDIX L

BIOGRAPHY

Julia A. Valentour

Julia is the daughter of James and Mary Ann Valentour, and the sister of Tom Valentour. She grew up in Richmond, Virginia where she actively participated in three high school varsity sports: Cross Country, Track, and Cheerleading. She turned down a Cross Country scholarship from Virginia Commonwealth University to attend the Virginia Polytechnic Institute and State University, where she majored in Liberal Arts. Wanting to continue to law school, her minors in that field were English, History, and Sociology. Because she enjoys drawing and sculpting, she also minored in studio art.

After graduation, Julia worked for several years as a manager for Lady Foot Locker in the Northern Virginia area. The first store that she was in charge of was in Georgetown, the northwest section of Washington, D.C. After a promotion, Julie relocated to manage a store in Hampton, VA. It was there that she was recruited to work for another retail company, American Eagle Outfitters. A promotion soon took her to Wilmington, N.C. There she opened and ran a new store, exceeding sales projections by $94,000 in just 9 months. After that, she decided on a career change to Sports and Exercise. At the University of North Carolina at Wilmington, she studied Sports Medicine, while working several part time jobs: a personal trainer at Gold’s Gym, a gymnastics instructor at the Coastal Tumblegym, and as a fitness technician
in Cardiac Rehab and Wellness at the New Hanover Regional Wellness Center.

Realizing that a master's degree was necessary in her field, Julia decided to attend Georgia Southern University in the fall of 1999. Upon completion of her master's degree, Julia will be entering the work force. A doctorate degree may follow in the upcoming years, but, like everything else she has done, she will take her time getting there.