1995

A submaximal test for arm ergometry to determine peak oxygen uptake rate in upper body exercise

Greg Asplund
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Asplund, Greg, "A submaximal test for arm ergometry to determine peak oxygen uptake rate in upper body exercise" (1995). *Master's Theses*. 1114.
DOI: <https://doi.org/10.31979/etd.a6tc-ctzh>
https://scholarworks.sjsu.edu/etd_theses/1114

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

**A SUBMAXIMAL TEST FOR ARM ERGOMETRY
TO DETERMINE PEAK OXYGEN UPTAKE RATE IN UPPER BODY
EXERCISE**

**A Thesis
Presented to
The Faculty of the Department of Human Performance
San Jose State University**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Arts**

**by
Greg Asplund
December, 1995**

UMI Number: 1377205

UMI Microform 1377205

Copyright 1996, by UMI Company. All rights reserved.

**This microform edition is protected against unauthorized
copying under Title 17, United States Code.**

UMI

**300 North Zeeb Road
Ann Arbor, MI 48103**

© 1995

Greg Asplund

ALL RIGHTS RESERVED

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

Dr. Craig Cisar

Dr. Nancy Megginson

Becky Williamson

APPROVED BY THE UNIVERSITY

ABSTRACT

A SUBMAXIMAL TEST FOR ARM ERGOMETRY TO DETERMINE UPPER BODY PEAK OXYGEN UPTAKE RATE

by Greg Asplund

A submaximal test for arm ergometry was developed to determine an estimate for peak oxygen uptake rate values for upper body exercise. Ten males and 10 females were tested, ages 21 - 35 years. Each subject completed a graded arm ergometer exercise test consisting of two minute intervals until a steady-state heart rate was achieved at a level between 60 - 70% of their predicted maximal heart rate. The test was then continued in 1 minute intervals to a maximal effort. Heart rate, workload, and gas analysis were monitored throughout the entire test. Independent t-tests revealed that the men had significantly ($p < .05$) higher steady-state workload, maximal workload, steady-state VO_2 , and $\text{VO}_{2\text{peak}}$ values. Pearson product-moment correlation coefficients indicated that $\text{VO}_{2\text{peak}}$ was significantly related to gender ($r = .88$), body weight ($r = .85$), and steady-state workload ($r = .76$). A multiple regression analysis demonstrated that the best equation for predicting $\text{VO}_{2\text{peak}}$ utilized the variables of gender, body weight, and steady-state workload. The multiple regression equation was as follows: $\text{VO}_{2\text{peak}} \text{ (L/min)} = 0.146 + 0.493(\text{gender}) + 0.017(\text{body weight}) + 0.004(\text{steady-state workload})$ ($R = .930$ and $\text{SEE} = 0.249 \text{ L/min}$).

Acknowledgments

I would like to thank the following people without whose help and support this project would have never been completed. Barb, my wife, who made time in her schedule for things that were above and beyond the call of duty so that I was able to have time to work, and also for her great editing skills. Dr. Craig Cisar, who was responsible for guiding me through all aspects of this thesis and taking time out of his schedule to help with data collection, revisions, and data analysis. Thanks, also to Jim Bowen for his help with the data collection on weekends and evenings. And finally, thanks to my 22 subjects who volunteered to give their best effort, and gave up some of their valuable time to enable me to conduct this research.

Table of Contents

<u>Chapter</u>	<u>Page</u>
I. Introduction.....	1
Background for the Study.....	1
Statement of the Purpose.....	4
Approach to the Problem.....	4
Statement of the Null Hypotheses.....	5
Delimitations.....	6
Assumptions.....	6
Definitions.....	6
II. REVIEW OF LITERATURE.....	9
Introduction.....	9
Arm Ergometry and Testing Protocols.....	9
Physiological Differences of Arm and Leg Ergometry.....	15
Physiological Responses of Women to Arm Ergometry.....	20
Summary.....	21
III. METHODS.....	26
Introduction.....	26
Subjects.....	26
Methods and Measurements.....	27
Prestest.....	27
Test Protocol.....	27
Measurements.....	29
Data Analysis.....	30

<u>Chapter</u>	<u>Page</u>
IV. DATA ANALYSIS.....	32
Introduction.....	32
Analysis of Data.....	32
Summary of Findings.....	37
Discussion of Findings.....	38
Conclusions.....	42
Weaknesses.....	42
Recommendations for Future Research.....	43
References.....	45
Appendices	
A. Consent Form.....	49
B. Medical History Questionnaire.....	52

List of Tables

	<u>Page</u>
1. Descriptive Characteristics of Subjects.....	33
2. Matrix of Correlation Coefficients.....	35
3. Multiple Regression Equations for Predicting VO_{2peak}	36

CHAPTER I

Introduction

This chapter will be organized to the following sections: background for the study, statement of the purpose, approach to the problem, statement of the null hypotheses, delimitations, assumptions, and definitions.

Background for the Study

Accelerated research in exercise physiology began in the 1920s at the Harvard Fatigue Laboratory. Since that time, many studies have been performed to test the physiological adaptations of the human body to exercise. Much of this research has been focused on the body's endurance capabilities. Through this research, it has been demonstrated that the most accurate method of assessing a person's endurance capabilities is by measuring how well they can maximally utilize oxygen, or VO_{2peak} .

There have been many dynamic exercise tasks that examine the subject's ability to utilize oxygen at progressive workloads to the point of VO_{2peak} . Until the 1970s, the focus of these tests was almost exclusively on the lower body muscle groups. Since the 1970s, increased effort has been directed toward the study of physiological responses to dynamic exercise tasks employing upper body muscle groups (Sawka, 1986).

Since exercise tests involving upper body tasks are relatively new, there is not a vast amount of research available regarding

accurate methods for assessing the aerobic capacity using only the upper body. While most of the general population can be accurately tested with lower body exercise, the use of upper body aerobic testing appears to be particularly applicable to selected populations. It is the belief of many researchers that upper body exercise testing may be more applicable to people who are involved with daily activity that primarily utilizes the upper body muscle groups (ACSM, 1991; Franklin, 1985; Sawka, 1986). Also, it is recognized in research that upper body testing may be more beneficial for individuals with peripheral vascular disease (Franklin, 1985; Franklin, Vander, Wrisely & Rubenfire, 1983; Sawka, 1986). There is also an interest in upper body exercise by space physiologists because astronauts, in their weightless state, do a substantial amount of work with their arms and hands (Sawka, 1986). Probably the most important reason for the study of upper body exercise testing is the need for evaluation and exercise prescriptions for individuals who are disabled and cannot utilize their lower body for ambulation (ACSM, 1991; Egger & Finch, 1988; Franklin, 1985; Glaser, Sawka, Brune & Wilde, 1980; Sawka, 1986). It is essential for the disabled population to develop greater upper body exercise capabilities in order to improve their wheelchair locomotion and other activities resulting in a better quality of life (Sawka, 1986).

Much of the recent research involving the upper body exercise testing has been done with arm ergometry. Through this research a variety of maximal arm ergometry tests have been designed and

employed in the assessment of oxygen uptake rate (Egger & Finch, 1988). Unfortunately, unlike leg ergometry, there are very few submaximal arm ergometry protocols available to provide an accurate estimation of oxygen uptake rate. Egger and Finch (1988) state that in order to reduce the potential risk associated with a maximal graded exercise test, it easily becomes apparent that a submaximal graded exercise test requiring substantial aerobic metabolism is needed to satisfactorily estimate one's aerobic capacity. Most researchers would agree that because of a variety of differences in the physiological adaptations between upper and lower body exercise, the utilization of lower body submaximal tests to predict upper body $\text{VO}_{2\text{peak}}$ would result in poor prediction results. Magel, McCardle, Toner, and Delio (1978) and Sawka (1986) agreed that because of specificity of training adaptations, it is extremely difficult to obtain a viable predicted peak oxygen uptake rate for upper body exercise by using prediction equations devised specifically for lower body muscle groups. In a review paper, Sawka (1986) stated that there is a clear need to develop submaximal tests to predict peak oxygen uptake rate for upper body exercise. Thus, a reliable submaximal test would allow exercise physiologists to achieve a better understanding of the body's physiological adaptations to upper body exercise as well as provide a great benefit to the previously mentioned populations in helping guide them safely in their exercise regimes.

Statement of the Purpose

The purpose of this study was to determine if the developed submaximal arm ergometry protocol provided an accurate estimate of $\text{VO}_{2\text{peak}}$, using heart rate, workload, age and gender as predictive factors, when compared with values obtained from a maximal arm ergometry test.

Approach to the Problem

The participants of this study were 22 aerobically conditioned volunteers between the ages of 18 and 40 years old. The maximal heart rate (PHRmax) was calculated by using the following formula: $\text{PHRmax} = 207 - \text{age in years}$. This formula was derived by using mean heart rate differences, between the upper and lower body, from studies in Franklin's (1985) review paper. The mean (13 bpm) of those studies selected by this author was then subtracted from 220 bpm, or the age-predicted maximal heart rate. The testing consisted of one session, with the subjects performing the submaximal test and then progressing to the maximal test after the submaximal values were obtained. The subjects each began with an initial workload of zero resistance for one minute to become acquainted with the pedal cadence of 50 rpm. The resistance increased to 150 kpm/min for two minutes and then increased by 150 kpm/min every two minutes until the subject's heart rate was equal to or greater than 100 bpm. After the heart rate of 100 bpm was achieved, the workload was increased by 75 kpm/min for each

two minute workload until the heart rate was between 60 and 70% of the subject's predicted HRmax for a period of two minutes and a steady-state heart rate was achieved (heart rates were within 5 bpm of each other on two consecutive minutes). After steady-state heart rate was achieved, the workload was increased by 75 kpm/min every minute until the subject was no longer able to maintain the pedal rate of 50 rpm. Gas samples were collected continuously throughout the test and heart rate values were obtained during the last 10 seconds of each minute. Predicted VO_{2peak} was estimated by using a multiple regression correlation equation utilizing the following factors; gender, heart rate, steady-state workload, body weight, age, predicted maximal heart rate, steady-state heart rate and oxygen uptake rate.

Statement of the Null Hypotheses

1. There will be no difference between males and females in the physiological parameters of body weight, steady-state heart rate, maximal heart rate, steady-state workload, maximal workload, steady-state VO_2 , VO_{2peak} , relative heart rate, and predicted maximal heart rate.
2. There will be no correlation between the dependent variable (VO_{2peak}) and the independent variables of age, body weight, gender, steady-state heart rate, steady-state workload, and predicted maximal heart rate.

3. The independent variables listed above will not be highly related, and therefore, not valid predictors of $\text{VO}_{2\text{peak}}$.

Delimitations

This study was limited to 22 healthy male and female volunteers aged 18 to 40 years. All subjects had been exercising aerobically at least three times per week for at least 30 minutes per session for at least two months prior to testing.

Assumptions

Assumptions made for this research were:

1. Subjects gave their best effort during the testing session.
2. Subjects complied with food intake and exercise restrictions prior to testing.

Definitions

The following definitions were used in this study:

Ergometer: a stationary bicycle on which the power output can be adjusted. Ergometers can be either electronically braked, where the power output remains fixed within a range for a specified rate of pedalling, or a mechanically loaded ergometer where the power output is directly related to the frictional resistance and rate of pedalling (McCardle, Katch, F., & Katch, V., 1991). This research utilized a mechanically loaded Monark 818 cycle ergometer.

Heart Rate (HR): Heart rate is the number of ventricular contractions as measured by an electrocardiogram (Astrand & Rodahl, 1986). Heart rate was measured during the last 10 seconds of each minute throughout the graded exercise test. Heart rate was expressed in beats per minute (bpm).

Maximal Test: An exercise test in which the subject is asked to perform to their maximal effort, in order to examine the limits of their physiological parameters.

Maximal Workload: The greatest resistance achieved on the ergometer during the maximal test (expressed in kpm/min).

Oxygen Uptake (VO₂): The volume of oxygen extracted by the body from inspired air, usually expressed in liters of oxygen per minute (L/min) or milliliters of oxygen per kilogram of body weight per minute (ml/kg/min) (Astrand & Rodahl, 1986).

Peak Oxygen Uptake Rate (VO_{2peak}): The point at which the oxygen consumption plateaus and shows no further increase (or increases only slightly) with an additional workload (McCardle et al., 1991).

Predicted Maximal Heart Rate (PHR_{max}): The predicted maximal heart rate that can be attained by each subject. This research used the following equation to predict maximal heart rate: $PHR_{max} = 207 - \text{age (years)}$.

Relative Heart Rate: The percent of the steady-state heart rate when compared to the predicted maximal heart rate.

Revolutions per Minute (RPM): The number of full turns by the arm ergometer crank in one minute.

Steady-State Heart Rate (SS HR): When the heart rates were within 5 bpm of each other on two consecutive minutes.

Steady-State Workload (SS WL): The amount of resistance on the cycle ergometer during the steady-state portion of the submaximal test (expressed in kpm/min).

Submaximal Test: A test used to predict physiological parameters for a maximal effort. A submaximal test is usually performed at or below 70% of VO_{2peak} or heart rate. When using a submaximal test to predict VO_{2peak} , a straight line can be drawn through several submaximum points that relate heart rate and oxygen consumption and then extending this line to some assumed maximum heart rate for the particular age group (McCardle et al., 1991).

CHAPTER II

Review of Literature

Introduction

This chapter includes information gathered from the review of literature covering the following topics: arm ergometry and testing protocols, both maximal and submaximal; physiological differences between arm and leg ergometry including oxygen uptake rate, peak power output and heart rate; and the physiological responses of women to arm ergometry.

Arm Ergometry and Testing Protocols

The use of leg ergometry in exercise testing with measurement of $\text{VO}_{2\text{peak}}$ has been used frequently for determining a person's aerobic capacity. In the last two decades, increased effort has been directed toward the study of physiological responses to dynamic exercise tasks employing upper body muscle groups (Sawka, 1986). This interest in upper body exercise testing has been brought about by reasons stated in the previous chapter. Arm cycle ergometry is the most common form of upper body exercise testing because it has been found to be reliable and reproducible in eliciting physiological responses (Bar-Or & Zwiren, 1975; Lazarus, Cullinane, & Thompson, 1981; Magel et al., 1980; Sawka, Foley, Pimental, Toner, & Pandolf, 1983). Sawka (1986) focused his review article on arm cycle ergometry as an upper body exercise test because: (a) it can easily be set up by modifying commercially available cycle

ergometers; (b) it is the most common mode of upper body ergometry reported in scientific literature; (c) it is the least physiologically complex form of upper body exercise; and (d) a knowledge of the physiological responses to arm-crank exercise is essential to understand the additional physiological burden imposed by other methods of upper body exercise, such as wheelchair exercise.

All of the studies reviewed used some form of a modified cycle ergometer. Usually, when arm-only exercise was being tested, the subject was seated in a chair directly behind the crank sprocket of the cycle ergometer. The majority of the studies had the subjects positioned so that they were seated with the midpoint of the chain sprocket in line with the shoulder, or glenohumeral joint (Bar-Or & Zwiren, 1975; Glaser et al., 1980; Reybrouck, Heigenhauser, & Faulkner 1975; Sawka et al., 1983; Vokac, Bell, Bautz-Holter, & Rodahl 1975; Walker, Powers, & Stuart, 1986). Miles, Cox, and Bomze (1984) used the positioning point of midsternum. Lazarus et al. (1981) had subjects positioned so the peak elevation of the handles were even with the acromion process. Cummins and Gladden (1983) experimented with different crank heights of above, below, and at heart level. The authors found no significant differences between the responses to submaximal and maximal arm cycling for either of the three positions. Sawka (1986) stated that conflicting findings regarding crank axis positioning demonstrated that the influence of positioning on eliciting physiological responses was not

well understood and merits additional research. It was the belief of this author that selection of a crank height axis even with the glenohumeral joint would allow for increased mechanical efficiency of that joint, insure proper biomechanical alignment for the motion performed, and would also provide an easily attainable landmark for future research. While there was conflicting information regarding the axis height, all of the research reviewed for this study agreed that the arm should reach a "slightly bent" position when the arm crank handle was at its furthest position from the body.

While there were very few variations in the actual positioning of the subjects, the argument of the optimal pedal rate ranged from 30 to 80 rpm with the vast majority using either 50 or 60 rpm. Jessup, Riggs, Lambert, and Miller (1977) found that there was no significant difference when using either 50 or 80 rpm for oxygen uptake values while using the Astrand-Ryhming test for leg ergometry. Another study which examined pedal rate and its influence on physiological responses found that a higher VO_{2peak} was attained with a 70 rpm pedal rate, when compared with rates of 30 and 50 rpm (Sawka et al., 1983). The authors believed that a faster crank rate would require less muscular tension at a given workload and therefore improve muscle perfusion and increase VO_{2peak} values. Walker et al. (1986) found that their "jump max" protocol for arm ergometry, with a pedal rate of 80 rpm, was better at eliciting VO_{2peak} and peak power output than a continuous protocol with a 40

rpm pedal rate and a discontinuous protocol with a 50 rpm pedal rate.

When one examines protocols for both maximal and submaximal arm ergometry, there appear to be advantages to both intermittent and continuous methodologies. According to the research, each method may have specific influences on physiological responses. Of the 17 arm ergometry protocols examined in this study, nine were continuous (CON), six were intermittent (INT) and two examined protocols using both continuous and intermittent methods. Sawka et al. (1983) examined an INT protocol (3-min workload followed by a 15-min rest period) at 50 rpm and a CON protocol (3-min workloads) at 30, 50 and 70 rpm for each test. The authors found that there was no significant difference in the $\text{VO}_{2\text{peak}}$ and maximal heart rate between the INT and CON protocols at 50 rpm. There was a significantly higher power output with the INT when compared to the CON at 50 rpm. It was also concluded in this study that a CON protocol at 70 rpm was the most effective at eliciting $\text{VO}_{2\text{peak}}$ values.

Walker et al. (1986) examined an INT, CON and their own "jump max" test to determine which protocol was best at eliciting $\text{VO}_{2\text{peak}}$. Their "jump max" test was started at a work rate which elicited a heart rate of 120 bpm (heart rate was determined by a pretest). The subjects were asked to keep a pedal rate of 80 rpm and increase their workload by 20 Watts each minute until they were no longer able to continue with the test. Their "jump max" test yielded

significantly higher peak power output and $\text{VO}_{2\text{peak}}$ values than both the INT and CON protocols which they tested. They also found that with the "jump max" test these peak values were attained in significantly less time than the other two tests. It was interesting to note that, while there was a break between the pretest and the maximal portion of the "jump max" test, it was basically an accelerated continuous protocol. It was also very difficult to decide from this study which method was the most advantageous because of the wide range of pedal rates used for each of the tests (CON - 40 rpm, INT - 50 rpm, and jump max - 80 rpm). As stated earlier in this chapter, studies have shown that pedal rate can have a significant influence on $\text{VO}_{2\text{peak}}$ and therefore it would be difficult to rely on the results of this study for determining the best protocol for eliciting $\text{VO}_{2\text{peak}}$.

Sawka (1986) stated that intermittent protocols yielded a higher power output than continuous protocols, but there were no significant differences in peak oxygen uptake rate responses between the two types of tests. The author also believed that continuous tests, as compared with intermittent tests, provided an obvious advantage in that less time is needed to administer the test. Based on the previous information, it would seem that the best method for this particular research would be the continuous protocol, since reduced administration time would be advantageous when using the test with a large number of people.

The determination of workload during arm ergometry is another area in which researchers needed to address the differences between upper and lower body exercise. Franklin (1985) stated that because arm exercise elicits higher heart rates and perceived exertion rates than leg exercise for a given workload, that workloads approximating 50% of the leg training values were appropriate for arm training workloads. The American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (1991) recommend that VO_2 for arm ergometry can be estimated with reasonable accuracy for work rates between 150 and 750 kpm/min, as compared to 300 to 1200 kpm/min for leg ergometry.

On examination of the maximal protocols available, it is very difficult to find a standard initial workload. Beginning workloads for maximal arm ergometry tests varied from zero resistance to a predetermined rate of a workload that elicited 70% of the subject's maximal heart rate (Sawka, 1986). Since even fewer studies utilized submaximal protocols, it became even more difficult to establish a base work rate. Cummins and Gladden (1983) examined submaximal responses for the arms, beginning with zero resistance and increasing each workload approximately 29 Watts per 10-min intermittent work stage. Egger and Finch (1988) began their submaximal exercise stage at 180 kpm/min and progressed by 90 kpm/min per 2.5-min stage until the subjects reached a heart rate of 170 bpm.

In contrast to these upper extremity maximal protocols, the lower extremity submaximal protocols tended to be more specific. The submaximal tests for leg ergometry used by the YMCA (Golding, Meyers, & Sinning, 1982) began with a workload of 150 kpm/min and then progressed at a workload ranging from 150 kpm/min to 600 kpm/min depending on the subject's heart rate at the end of the previous workload. This method allowed the researcher to adjust each workload to conform to the variability of the individual subjects in order to reach a desired submaximal steady-state heart rate of 110 to 150 bpm for two consecutive workloads.

Physiological Differences of Arm and Leg Ergometry

The physiological differences between arm and leg ergometry are numerous. Many researchers (Astrand & Saltin, 1961; Bergh, Kanstrup, & Ekblom, 1976; Franklin, 1985; Keyser, Mor, & Andres, 1989; Lazarus et al., 1981; Pendergast, 1989; Reybrouck et al., 1975; Sawka, 1986; Toner, Sawka, Levine, & Pandolf, 1985; Vokac et al., 1975) have compared the physiological parameters that will be examined in this study (i.e., oxygen uptake rate, power output, and heart rate) and have discovered that there were significant differences in these physiological responses when performing the two modes of exercise. Because of these differences it was unreliable to use oxygen uptake rate figures obtained from arm ergometry to predict $\text{VO}_{2\text{peak}}$ for leg ergometry in the same individual.

The difference between arm and leg exercise was very evident when comparing peak oxygen uptake rate during exercise. The highest oxygen uptake rate achieved by men and women during arm exercise was generally about 70 to 80% of the maximal oxygen uptake rate for leg exercise (McCardle et al., 1991). Astrand and Saltin (1961) found that maximal work with the arms yielded only 70% of the oxygen uptake rate in the legs and attributed this difference to the smaller muscle mass that was in use during arm exercise. Similar results were found by Franklin et al. (1983, 80%), Reybrouck et al. (1975, 68%), Bergh et al. (1976, 73%) and Vokac et al. (1975, 78%). In Franklin's (1985) review article, the author found there was a mean ratio of 72% when comparing the maximal oxygen uptake rate values achieved by arm ergometry when compared to leg ergometry. Sawka (1986) found in his review article that there was a mean ratio of 73% among the research studies examined. This difference again, could be due to a smaller muscle mass in the upper body which would reduce the amount of oxygen that can be consumed by that particular muscle group.

Research has also shown that individuals who train their upper body muscle groups are more likely to produce upper body $\text{VO}_{2\text{peak}}$ values closer to those values achieved by their legs. Research has indicated that subjects who specifically train their upper body muscles can achieve arm-crank values approaching 90% of their leg cycle exercise peak oxygen uptake rate values. On the other hand, subjects who are sedentary may achieve only 60% of their leg cycle

exercise peak oxygen uptake values during arm-crank exercise (Sawka, 1986). The results indicate $\text{VO}_{2\text{peak}}$ for arm exercise may not be lower only because of a smaller muscle mass in the upper body but also could be attributed to the relative degree of conditioning between the upper and lower extremities (Reybrouck et al., 1975).

While $\text{VO}_{2\text{peak}}$ was reported to be lower in arm exercise than in leg exercise, the relationship of oxygen uptake rate to power output is greater for the upper body for a given submaximal workload (Franklin, 1985; Sawka, 1986). Franklin et al. (1983) found that VO_2 values were 25-33% greater for arm work than leg work at workloads at or greater than 450 kpm/min. Vander, Franklin, Wisely, and Rubenfire (1984) found significantly higher VO_2 values for arm exercise at any submaximal workload and Vokac et al. (1975) found similar results for arm exercise at or greater than 600 kmp/min. Franklin et al. (1983) stated that this response was attributed in part to the isometric stabilizing effort required with arm work. This increased effort increases VO_2 but does not affect the external work output.

Another difference between VO_2 values attained during arm and leg exercise was found in a study by Reybrouck et al. (1975). They found that VO_2 values have a tendency to level off once a maximal work rate was achieved and this leveling off was more easily obtained during leg ergometry than during arm ergometry. The authors believed this occurred because muscles with a relatively

low $\text{VO}_{2\text{peak}}$ also have limited capacities for anaerobic metabolism and a plateau in $\text{VO}_{2\text{peak}}$ would require the generation of energy by anaerobic pathways.

Smaller muscle mass and reduced mechanical efficiency were not only responsible for higher VO_2 values for submaximal workloads, but they also influenced the peak power output values for arm ergometry. Sawka (1986) reported that gross and net efficiency indices were lower during arm-crank than leg cycle exercise. When examining arm and leg ergometry in women, Vander et al. (1984) found that maximal workload during arm ergometry was only 48% of the maximal workload during leg ergometry. Franklin et al. (1983) found that peak workload for men was only 55% for arm ergometry as compared to leg ergometry. Vokac et al. (1975) found subjects could only endure arm-crank workloads that were 50-60% of that in leg ergometry, and sometimes the maximal arm trials had to be shortened due to localized fatigue and intense pain.

Heart rate responses have been reported to be very similar to VO_2 responses when comparing arm and leg ergometry. Researchers generally agreed that peak heart rate was significantly lower in arm ergometry when compared to leg ergometry (Astrand & Saltin, 1961; Bar-Or & Zwiren, 1975; Reybrouck et al., 1975; Sawka et al., 1983). While the research reported a difference between the peak heart rate of arm and leg ergometry, there was wide variation in the results of different studies as to the magnitude of the difference. Of the studies reviewed for this research, the lowest difference

between arm and leg ergometry was 8 bpm (Vander et al., 1984) and the largest difference was 22 bpm (Bar-Or & Zwiren, 1975), with the mean difference of 14 bpm. These figures compared well with a mean difference of 14 bpm found in Franklin's (1985) review paper on arm ergometry. These findings regarding heart rate responses were especially important when considering an exercise prescription for the upper body. Vander et al. (1984) stated that an arm exercise prescription which assumed a maximal heart rate equivalent to that during leg exercise testing may result in an over-estimation of the training heart rate.

For arm ergometry, the heart rate responses were similar to oxygen uptake rate responses during submaximal workloads. Pendergast (1989), Franklin et al. (1983), Toner et al. (1985), and Vander et al. (1984) all found that heart rate was significantly higher in arm ergometry than leg ergometry for a given submaximal workload. Sawka (1986) stated that investigators consistently report a higher heart rate for a given submaximal oxygen uptake rate during arm-crank exercise as compared to leg cycling exercise. Even though cardiac output is the same for both types of exercise, arm ergometry induced a higher heart rate and lower stroke volume than leg ergometry. Sawka felt that this was due to differences in cardiac filling, or preload, caused by reduced skeletal muscle pumping activity during arm ergometry. The same factors may also be involved in a the more rapid increase in heart rate, observed by

Reybrouck et al. (1975), during submaximal arm ergometry in comparison to submaximal leg ergometry.

Physiological Responses of Women to Arm Ergometry

Of the studies reviewed for this research, only one was found which addressed arm ergometry testing of women. Vander et al. (1984) found that heart rate and VO_2 were significantly greater as compared to leg exercise at a given submaximal workload. Maximal heart rate, $\text{VO}_{2\text{peak}}$, and workload were significantly less in arm ergometry, with this $\text{VO}_{2\text{peak}}$ reaching 78% of the $\text{VO}_{2\text{peak}}$ achieved during leg ergometry. All of the comparisons between arm and leg ergometry in this study were very similar to the physiological factors discussed earlier in this chapter for male subjects. While $\text{VO}_{2\text{peak}}$ was considerably lower for both arm and leg exercise when comparing the women's results to results obtained from research done on men, it was discovered that the ratio of upper extremity to lower extremity $\text{VO}_{2\text{peak}}$ was comparable in men and women. With these findings, the authors concluded that it seemed women's cardiorespiratory aerobic capacity for arm work was not disproportionately inferior to men's, contrary to generally accepted opinion. Thus, after viewing this study, it would seem that one could expect similar physiological responses to arm ergometry in both men and women.

Summary

Arm cycle ergometry is the most common form of upper body exercise testing because it has been found to be reliable and reproducible in eliciting physiological responses (Bar-Or & Zwiren, 1975). It is useful because it can easily be adapted from lower extremity cycle ergometers and is the least physiologically complex form of upper body exercise. Also, arm ergometry plays an essential part in understanding upper body physiology in order to gain further knowledge that can be applied towards methods of training such as wheelchair exercise. All of the studies reviewed used some form of a modified lower extremity cycle ergometer. The most common positioning of the subject was with the midpoint of the chain sprocket in line with the gleno-humeral joint (Bar-Or & Zwiren, 1975; Glaser et al., 1980; Reybrouck et al., 1975; Sawka et al., 1983; Vocak et al., 1975; Walker et al., 1986). Cummins and Gladden (1983) found no significant differences in the physiological responses with crank heights of above, below, and at heart level. There was no evidence in the literature that pointed to crank level as having a great influence on the physiological responses of arm ergometry (Sawka, 1986). All research articles reviewed for this study agreed that the subject should be positioned so that the arm can reach a "slightly bent" position when the hand crank is at its furthest distance from the body. Pedal rates varied from 30 to 80 rpm in the literature reviewed, with the majority using 50 or 60 rpm. Sawka et al. (1983) and Walker et al. (1986) found that higher

pedal rates (70 and 80 rpm, respectively) elicited greater $\text{VO}_{2\text{peak}}$ values.

Both intermittent and continuous protocols have advantages for arm ergometry testing. Sawka et al. (1983) found no significant difference between an intermittent and continuous protocol when comparing $\text{VO}_{2\text{peak}}$ and maximal heart rate. They also found a significantly higher power output for the intermittent protocol as compared to the continuous protocol. The main advantage of a continuous protocol was that it took less time to administer (Sawka, 1986). Walker et al. (1986) examined a modified continuous protocol, called the "jump max" test, and found that this protocol enabled subjects to yield a higher peak power output and higher $\text{VO}_{2\text{peak}}$. The problem with this study was that all three tests were done at different pedal rates, which has been proven by previous studies to affect peak physiological parameters. It is clear that different protocols can and do elicit different responses in subjects participating in arm ergometry, but further research is needed to find exactly what effects each type of protocol has on the above mentioned physiological responses.

Initial workloads for submaximal arm ergometry tests were recommended to be approximately 50% of those used in leg ergometry (ACSM, 1991; Franklin, 1985). This was due to a smaller muscle mass required in arm ergometry, thus limiting the overall power output for the upper body muscle groups. The progression from the initial workload was either done in even increments (Egger

& Finch, 1988) or by different workload stages determined by the subject's heart rate during each testing stage (Golding et al., 1982). As in leg ergometry, the subjects continued at these progressive workloads until their heart rate was at a steady-state and is within a range of 50-80% of maximal heart rate.

When examining the difference in physiological responses between the arms and the legs, significant differences can be found in oxygen uptake rate, work output, and heart rate at all levels of exercise. $\text{VO}_{2\text{peak}}$ ratios ranged from 68% (Reybrouck et al., 1975) to 80% (Franklin et al., 1983) when comparing arm to leg values for oxygen uptake rate. In review articles by Franklin (1985) and Sawka (1986), the authors found mean arm/leg $\text{VO}_{2\text{peak}}$ ratios of 72% and 73%, respectively. Furthermore, subjects who train their upper body muscle groups have been found to achieve $\text{VO}_{2\text{peak}}$ values approaching 90% of their leg $\text{VO}_{2\text{peak}}$ values with arm ergometry (Sawka, 1986).

The relationship of oxygen uptake rate to power output for arm and leg ergometry was significantly higher for arm exercise than leg exercise at a given submaximal workload above 450 kpm/min. Franklin et al. (1983) found VO_2 values were 25-33% greater for arm work as compared to leg work. This response can be attributed to the greater isometric stabilizing factor involved in arm ergometry, which would increase the VO_2 without contributing to the external work output.

Peak workload for arm ergometry was also reported to be less than the values achieved by leg ergometry. Franklin et al. (1983)

found peak workloads of only 55% and Vander et al. (1984) found peak workloads of 48% for women when comparing arm work to leg work.

Heart rate responses were very similar to VO_2 responses when comparing the two types of ergometry. Peak heart rate responses were 10 to 15 bpm lower in arm ergometry than in leg ergometry (ACSM, 1991). In review articles done by Sawka (1986) and Franklin (1985), the authors found a mean difference between arm and leg ergometry to be 8 bpm and 14 bpm, respectively. Heart rate responses were also similar to oxygen uptake rate in that they were significantly higher in arm exercise than leg exercise for a given workload.

The research concerning women's responses to arm ergometry was even less than for the men, as there has been only one article found for this review which compared women's physiological responses between arm and leg ergometry. Vander et al. (1984) found women's responses were very similar to those of men studied under the same experimental circumstances; therefore, similar physiological responses in both men and women would be expected. The authors also demonstrated that the upper extremity/lower extremity ratio of $\text{VO}_{2\text{peak}}$ was not disproportionately inferior to men's as has been previously believed. As with arm ergometry in general, the area of women's responses to arm exercise is definitely an area in need of further research.

Upon conclusion of reviewing the literature, the findings noted above were the basis for developing a submaximal arm ergometry protocol which could easily be reproduced in research and would provide a valid estimate of a person's $\text{VO}_{2\text{peak}}$ values for upper body exercise. As stated earlier, our knowledge of upper body aerobic capacities has been very limited in comparison to lower body aerobic capacities. Research has not demonstrated an effective method to predict upper body aerobic capacity as they have repeatedly done for lower body muscle groups. Since there is a large population of subjects who would benefit from obtaining an estimation of their upper body aerobic capacity from a submaximal test, it would seem that there is a great need for research that would contribute to this body of knowledge.

CHAPTER III

Methods

Introduction

This chapter presents information on the subjects, as well as the methods and measurements used in this investigation.

Subjects

The experimental protocol for this study has been approved by the San Jose State University Human Subjects Institutional Review Board. Subjects were solicited verbally and through posted advertisement. Twenty-two male and female subjects were tested for this study. Each subject was screened via questionnaire (Appendix B) for age, gender, medical history, family health history, and exercise training routines. Only those considered "apparently healthy" by the standards set in the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (4th edition, 1991) were used in this study.

Only active volunteers (those who exercise aerobically for a minimum of 30 minutes at least three times per week) were selected, since the level of fitness can alter a person's ability to utilize oxygen while exercising as well as affect their heart rate at a given submaximal workload (Sawka, 1986). Volunteers were each informed of the procedures and the possible risks of participating in this research, and subject consent (Appendix A) was obtained before initiation of testing.

Methods and Measurements

The 22 subjects each performed a submaximal and maximal arm ergometry test in the same testing session to determine predicted and actual oxygen uptake rate values, respectively. Each subject reported to the laboratory for one testing session. The submaximal test was performed at the start of the testing session with the maximal test continuing after a steady-state heart rate was attained between 60-70% of the subject's predicted maximal heart rate.

Pretest

Subjects were instructed not to eat or drink (except for water) in the three hours prior to testing and to not exercise twelve hours prior to testing (ACSM, 1991).

Testing Protocol

Prior to performing the arm ergometry test, the subject's body weight was measured in kilograms (kg) on a platform scale. Age was also calculated in years, to the nearest month. Predicted maximal heart rate was calculated by the following formula:
$$\text{PHR}_{\text{max}} = 207 - \text{age in years}.$$

The testing protocol for the arm ergometry test was a progressive continuous exercise method using a Monark 818 cycle ergometer at a pedal rate of 50 revolutions per minute (rpm). The

pedals of the cycle ergometer were replaced with hand grips to allow pedalling with the arms. The subjects were seated behind the cycle with the middle of the cycle sprocket even with the glenohumeral joint. The distance between the subject and the hand cranks was determined by the subject's arms reaching full extension at the crank's furthest position from the body. The subject sat with their legs comfortably positioned and the knees bent in a normal sitting position. Before the test began, the subjects were each informed of the testing procedures and were given the opportunity to ask questions.

Each subject performed a 1-min warm-up at zero resistance to become accustomed to the pedal cadence and use of the arm cycle ergometer. After the warm-up period, the first workload was set at 150 kpm/min for a two minute period. If the subject's heart rate was less than 100 bpm at the end of the first workload, the second workload was increased by 150 kpm/min. If the heart rate was greater than 100 bpm, the workload was increased by 75 kpm/min. After the subject's heart rate passed 100 bpm the workload was increased by 75 kpm/min every two minutes. When the subject's heart rate reached a point between 60-70% of their predicted maximal heart rate an additional one to two minutes was required at that workload, in some cases, to achieve a steady-state heart rate. After the subject achieved a steady-state heart rate between 60-70% of their predicted maximal heart rate the workload was increased by 75 kpm/min every minute until the subject was no

longer able to maintain the crank rate of 50 rpm. The test was terminated if : (a) the subject elected or was unable to continue; (b) the equipment failed; (c) the ECG showed abnormalities; and/or (d) signs of distress were indicated by loss of coordination (ACSM, 1991). After the maximal test, the subject was given a cool-down period, pedalling at zero resistance until the heart rate had decreased to below 120 bpm. Heart rate was monitored for the last 10 seconds of each minute throughout the duration of the test. Gas samples were collected and analyzed continually for the entire testing session. Measurements and monitoring of equipment was performed by three technicians during each testing session.

Measurements During the Arm Ergometry Test

The subject's heart rate was measured by using a standard 5 - lead (right arm, left arm, right leg, left leg, and V5) electrode lead placement (ACSM, 1991). Electrodes were connected to a Cardiofax V electrocardiogram monitor (model number ECG-8330A). An electrocardiogram (ECG) was printed (paper speed of 25 mm per minute) for the last 10 seconds of each minute during the test.

The subject wore a mouthpiece attached to a pneumotachometer of a Medgraphics Cardiopulmonary Exercise System (CPX/D) manufactured by Medical Graphics Corporation, St. Paul, MN. The CPX/D continuously measured breath-by-breath ventilation rate, and fraction of oxygen and carbon dioxide in the expired air, from which VO_2 and VCO_2 concentrations were

calculated. Steady-state VO_2 was calculated using the mean of each 30-sec period VO_2 uptake rate value during the steady-state workload period. $\text{VO}_{2\text{peak}}$ was determined as the highest 30-sec VO_2 value obtained during the final stage of the incremental arm ergometer test. Maximal heart rate was determined as the highest heart rate reached during the graded exercise test. Steady-state heart rate was calculated by the mean of the heart rate values for each minute during the workload in which the subject's heart rate was between 60-70% of their predicted maximal heart rate (PHRmax). Steady-state workload was determined by the amount of resistance on the ergometer (kpm/min) when the subject achieved a steady-state heart rate between 60-70% of their PHRmax. Relative heart rate was the percentage of the steady-state heart rate compared to the PHRmax. Maximal workload was the highest resistance (kpm/min) recorded during the graded exercise test. All subjects in this study achieved at least one of the criteria for indicators that the oxygen consumption was near-maximum (McCardle et al., 1991). These criteria were: (a) a plateau in VO_2 values; (b) the heart rate was within 10 bpm of PHRmax, and (c) the respiratory exchange ratio was above 1.0.

Data Analysis

Descriptive statistics, means and standard deviations, were used to describe the characteristics of age, body weight, steady-state heart rate, maximal heart rate, steady-state workload,

maximal workload, steady- state VO_2 , VO_{2peak} , relative heart rate, and predicted maximal heart rate in the male and female subjects, as well as the whole group. Independent t -tests were used to compare the characteristics of the male and female data. For the data of the total group, Pearson product-moment correlations were performed to examine the relationships between the independent variables (age, body weight, gender, steady-state heart rate, steady-state workload, and predicted maximal heart rate) and the dependent variable (VO_{2peak}).

Stepwise multiple regression analyses was used to develop regression equations for predicting the dependent variable of VO_{2peak} , from the independent variables of gender, body weight, and steady-state workload. In addition to the calculation of multiple correlation coefficients (R), standard error of estimates ($SEE = SD_y \sqrt{1-R^2}$) were also calculated from the multiple regression analyses.

Interpretation of the independent variables as valid predictors of VO_{2peak} were based on $R \geq .80$ and a low SEE . A correlation of $\geq .80$ or higher between the measures of the independent and dependent variables meets the minimum criterion of $.80$ for establishing validity on tests of physical fitness (Baumgartner & Jackson, 1991). The alpha level for statistical significance was $p \leq .05$ or less.

CHAPTER IV

DATA ANALYSIS

Introduction

This chapter will present information pertaining to the level of significance, analysis of data, summary of findings, discussion of findings, conclusions, weaknesses, and recommendations for future research.

Analysis of Data

Twenty-two healthy subjects were tested in this study (11 men and 11 women). Data from one man and one woman were not analyzed due to equipment difficulties during testing. The data from twenty subjects (10 men and 10 women) were analyzed.

Table 1 summarizes the descriptive characteristics of the subjects. Means and standard deviations were calculated for the total group as well as both men and women separately. The t -values were calculated between the male and female groups. Significant differences ($p < .05$) between men and women were revealed for the independent variables of age, body weight, steady-state heart rate, maximum heart rate, steady-state workload, maximum workload, steady-state VO_2 , relative heart rate, predicted maximum heart rate and the dependent variable $\text{VO}_{2\text{peak}}$. The men were significantly higher than the women when comparing body weight, steady-state workload, maximum workload, steady-state VO_2 , and $\text{VO}_{2\text{peak}}$.

TABLE 1.

Descriptive Characteristics of the Subjects

	total group		Women		Men		t value
	20		10		10		
Sample size							
Age (yr)	26.13 ± 4.43		25.29 ±	3.54	26.98 ±	5.23	0.85
Body Weight (kg)	70.98 ± 13.42		60.67 ±	8.72	81.30 ±	8.23	5.44*
SS HR (bpm)	120.03 ± 7.05		119.95 ±	9.05	120.10 ±	4.78	0.05
HRmax (bpm)	174.95 ± 14.81		176.70 ±	12.56	173.20 ±	17.27	0.52
SS WL (kpm/min)	105.00 ± 36.81		80.00 ±	25.82	130.00 ±	28.38	4.12*
Max WL (kpm/min)	223.75 ± 52.24		180.00 ±	34.96	267.50 ±	16.87	7.13*
SS VO ₂ (L/min)	1.12 ± 0.40		0.84 ±	0.21	1.39 ±	0.34	4.41*
VO _{2peak} (L/min)	2.07 ± 0.62		1.54 ±	0.31	2.60 ±	0.30	7.77*
Relative HR	69.20 ± 8.24		68.28 ±	7.89	70.11 ±	8.91	0.49
PHRmax (bpm)	180.87 ± 4.43		181.71 ±	3.54	180.02 ±	5.23	0.47

* p < .05

A correlation matrix containing both descriptive measures and physiological responses during the testing is presented in Table 2. Body weight and gender were both strongly related to $\text{VO}_{2\text{peak}}$ with correlation coefficients of .85 and .88, respectively. A moderately high correlation, .79, existed between body weight and gender. Steady-state workload and $\text{VO}_{2\text{peak}}$ also had a moderately high relationship with a correlation coefficient of .76. Furthermore, moderate relationships were revealed between steady-state workload and the variables of body weight and gender with correlation coefficients of .60 and .70, respectively. Other intercorrelations were relatively low or were not significant to this study.

Table 3 represents the multiple regression analyses for determining $\text{VO}_{2\text{peak}}$. Gender was a significant predictor in all three multiple regression equations and was the only variable used in equation 1, resulting in a multiple correlation coefficient (R) of .878 and a standard error of estimate (SEE) of 0.306 L/min. The addition of body weight as a variable significantly improved the prediction of $\text{VO}_{2\text{peak}}$ in equation 2 with $R = .913$: $SEE = 0.268$ L/min. The predictor variable of steady-state workload, when combined with gender and body weight, further improved the prediction of $\text{VO}_{2\text{peak}}$ with $R = .930$: $SEE = 0.249$ L/min.

TABLE 2.

Matrix of Correlation Coefficients

	1	2	3	4	5	6	7
1. Age	1.00						
2. Body Weight	.17	1.00					
3. Gender	.20	.79*	1.00				
4. SS HR	-.36	.15	.01	1.00			
5. SS WL	.23	.60*	.70*	.31	1.00		
6. VO _{2peak}	.23	.85*	.88*	.07	.76*	1.00	
7. PHRmax	-1.00*	-.17	-.20	.36	-.23	-.23	1.00

* $p < .05$

TABLE 3.

Multiple Regression Equations for Predicting VO_{2peak}

Equation 1 ($R = .878$; $SEE = 0.306$ L/min)

$$VO_{2peak} \text{ (L/min)} = 1.540 + 1.063(\text{gender})$$

Equation 2 ($R = .913$; $SEE = 0.268$ L/min)

$$VO_{2peak} \text{ (L/min)} = 0.393 + 0.673(\text{gender}) + .019(\text{body weight})$$

Equation 3 ($R = .930$; $SEE = 0.249$ L/min)

$$VO_{2peak} \text{ (L/min)} = 0.146 + 0.493(\text{gender}) + 0.017(\text{body weight}) \\ + 0.004(\text{steady state workload})$$

NOTE: Gender coded as female = 0, male = 1; body weight measured in kg; workload measured in kpm/min.

Summary of Findings

Independent *t*-tests revealed significantly higher values for the men as compared to the women when examining the variables of body weight, steady-state workload, maximum workload, steady-state VO_2 , and $\text{VO}_{2\text{peak}}$. No significant differences were discovered for age, steady-state heart rate, maximum heart rate, relative heart rate, and predicted maximum heart rate.

A strong correlation existed between the dependent variable of $\text{VO}_{2\text{peak}}$ and gender, as well as a strong relationship between body weight and $\text{VO}_{2\text{peak}}$. Steady-state workload had a moderately high relationship when compared to $\text{VO}_{2\text{peak}}$. Also, a moderately high correlation existed between the variables of body weight and gender. Moderate relationships were revealed between the variable of steady-state workload and both body weight and gender.

Multiple regression analyses demonstrated that gender was a significant predictor in all three equations used to predict $\text{VO}_{2\text{peak}}$. Equation 1 used only the variable of gender resulting in $R = .878$: $\text{SEE} = 0.306$ L/min. The equation using the variables of both gender and body weight improved the prediction of $\text{VO}_{2\text{peak}}$ to $R = .913$: $\text{SEE} = 0.268$ L/min. The multiple regression analysis determined that the best predicting factors of $\text{VO}_{2\text{peak}}$ were gender, body weight, and steady-state workload, with an $R = .930$: $\text{SEE} = 0.249$ L/min.

Discussion of Findings

The purpose of this study was to determine if the developed submaximal arm ergometry protocol provided an accurate measurement of VO_{2peak} when compared with the values obtained from the maximal arm ergometry test. Independent t -tests revealed a significantly higher workload for the men than the women in both steady-state workload and maximal workload. These findings are in agreement with Vander et al. (1984), who found that workload values are significantly higher for men when compared to women for a given upper body exercise. This difference is documented throughout exercise physiology literature and may be due to a greater lean body mass for men, which would enable a greater force to be applied by the working muscles during exercise (McCardle et al., 1991). McCardle et al. (1991) also pointed out that there was some evidence that the gender differences, for upper body strength, may be more biological in nature but more research is needed in this area. The independent t -tests also revealed a significant difference between the two groups, with the men attaining higher values, when examining the variables of steady-state VO_2 and VO_{2peak} . As with the workload values, these differences can be explained by a greater lean body mass in men which would require a greater oxygen uptake rate for a relative workload during exercise (McCardle et al., 1991; Vander et al., 1984). There were no significant differences between the men and the women in any of the variables concerning heart rate

(steady-state heart rate, maximal heart rate, relative heart rate at steady-state, and predicted maximal heart rate).

When examining the relative heart rate at steady-state workload, the results illustrate the mean percentage for the whole group of subjects at steady-state was $69.20 \pm 8.24\%$ of predicted maximal heart rate. These figures agreed with protocols recommended by Sawka et al. (1983). Astrand and Ryhming (1954) suggested in their conclusions that a heart rate during steady-state between 125 and 170 bpm was best for estimating peak VO_2 values from a submaximal level in leg ergometry exercise. The YMCA leg ergometry protocol for estimating $\text{VO}_{2\text{peak}}$ recommended a submaximal steady-state heart rate of 110 to 150 bpm (Golding et al., 1982). These values were also in agreement with the steady-state heart rate values of 120.03 ± 7.05 bpm achieved during this study when taking into consideration an estimated maximal heart rate of 13 bpm lower for arm exercise when compared to leg exercise.

When compared to the dependent variable of $\text{VO}_{2\text{peak}}$, the correlations from this study that registered as high relationships were body weight and gender. Both of these high correlations can be explained, as in previous paragraphs, because generally a person with greater body weight would elicit higher VO_2 values as a result of greater lean body mass that increases the need for higher oxygen consumption during exercise. A moderately high correlation was discovered between steady-state workload and $\text{VO}_{2\text{peak}}$. Astrand and

Ryhming (1954) discovered a high correlation when performing submaximal work between heart rate and maximal oxygen uptake rate, for both treadmill exercise and lower body cycle ergometry. Since this study used heart rate for determining the submaximal workload, this correlation can also be partially explained as a function of heart rate values during a submaximal work level. Steady-state workload was moderately correlated with both body weight and gender, once again pointing to the fact that a greater lean body mass will elicit higher workload levels at a given submaximal or maximal work level.

Because of its high correlation with the dependent variable VO_{2peak} , gender was the principal variable selected for all three multiple regression equations. Equation 1 uses only the variable of gender to predict VO_{2peak} , while equation 2 utilizes both of the variables, gender and body weight, that were highly correlated with the predicted variable and improved the regression equation from a $R = .878$ and a $SEE = 0.306$ L/min to a $R = .913$ and $SEE = 0.268$ L/min. The predictability of VO_{2peak} was further improved by adding the moderately high correlated variable of steady-state workload. Equation 3 had a $R = .930$ with a $SEE = 0.249$ L/min. The coefficient of determination (R^2) for Equation 3 revealed that the independent variables gender, body weight, and steady-state workload accounted for 86% of the variance in the prediction of VO_{2peak} . Egger and Finch (1988) used the predictor variables of body weight, age, workload, and heart rate for their multiple regression equation to predict

VO_{2peak} , which had a $R = .58$ and $SEE = 0.34$ L/min. The predictor variables of age and heart rate did not figure into the multiple regression equations for this study, but were a factor in calculating the steady-state workload. This workload was predicted by using a heart rate of 60-70% of the predicted maximal heart rate. The maximal heart rate was predicted by the following equation:
 $PHR_{max} = 207 - \text{age (years)}.$

Zwiren, Freedson, Ward, Wilke, and Rippe (1991) mentioned that many cycle ergometer tests have a tendency to overestimate actual VO_{2peak} values when using submaximal heart rate as a predictor. On the other hand, Rowell, Taylor, and Wang (1964) found that the Astrand-Ryhming method tended to underestimate actual VO_{2peak} values. The previously mentioned authors agreed that these differences, between actual and estimated values, were due to a more curvilinear, as opposed to a linear relationship, which was the previously assumed pattern of the HR- VO_2 relationship. Sawka (1986) reported on research that compared upper body values that were compared with estimates made from the Astrand-Ryhming model and found only a moderate ($r = .67$) correlation between the predicted and measured VO_{2peak} values. While the present study did utilize a submaximal heart rate to estimate the submaximal workload, as did the Astrand-Ryhming (1954) method of using a "nomogram" type of estimation method, the variable of heart rate was not directly utilized in the multiple regression equations. Therefore, the equations were not subject to the variations in the

HR-VO₂ relationship that were used in many of the oxygen consumption estimates previously employed for leg ergometry. Because of the physiological differences between upper and lower body exercise mentioned earlier in this paper, it would be interesting to determine if a similar curvilinear HR-VO₂ relationship existed in upper body exercise.

Conclusions

Within the limits of this study the following conclusions were made:

- (1) There were significant differences between men and women when examining the variables of steady-state workload, maximal workload, steady-state VO₂, and VO_{2peak}, with the men attaining higher values for all of these variables.
- (2) High correlation coefficients existed between the dependent variable of VO_{2peak} and the independent variables of gender and body weight. A moderately high relationship existed between steady-state workload and VO_{2peak}.
- (3) The best multiple regression equation for predicting VO_{2peak} utilized the predictor variables of gender, body weight, and steady-state workload.

Weaknesses

The subjects in this study were all able bodied, physically active, and between the ages of 21.32 and 34.90 years of age. Given

these parameters the results of this research should not be indiscriminantly utilized to represent the following populations:

(1) Individuals who have limited use of their lower trunk muscles and leg muscles for stabilization. (With this testing procedure it was impossible to limit all of the cranking power generated by the subjects to include only the arm and shoulder muscles and some subjects may have been aided by their trunk and leg muscles to differing degrees.)

(2) Individuals who perform physical work primarily with their upper body muscle groups or athletes who primarily train their upper body muscle groups.

(3) Sedentary individuals or individuals who do not exercise aerobically on a regular basis.

(4) Individuals who are younger or older than the subjects used in this study.

Recommendations for Future Research

In order to expand the body of knowledge regarding submaximal exercise testing to predict $\text{VO}_{2\text{peak}}$ values from arm ergometry, the following recommendations were made.

(1) Future research should attempt to cross-validate the equations developed in this study on populations with physical disabilities.

(2) Gathering data from subjects who do not participate in aerobic activity on a regular basis would add additional information to the body of knowledge of exercise testing using arm ergometry.

(3) Data from subjects who use or train primarily their upper body muscle groups on a daily basis would add additional information to the body of knowledge of exercise testing using arm ergometry.

(4) Furthermore, data from younger and older populations would add additional information to the body of knowledge of exercise testing using arm ergometry.

(5) Future research should examine the HR-VO₂ relationship for arm ergometry.

References

- American College of Sports Medicine (1991). Guidelines for exercise testing and prescription. Philadelphia: Lea & Febiger.
- Astrand, P., & Rodahl, K. (1986). Textbook of Work Physiology: Physiological Bases of Exercise (3rd ed.). San Francisco: McGraw-Hill.
- Astrand, P. O., & Ryhming, I. (1954). A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. Journal of Applied Physiology, 7, 218-221.
- Astrand, P. O., & Saltin, B. (1961). Maximal oxygen uptake and heart rate in various types of muscular activity. Journal of Applied Physiology, 16, 977-981.
- Bar-Or, O., & Zwiren, L. D. (1975). Maximal oxygen consumption test during arm exercise - reliability and validity. Journal of Applied Physiology, 38, 424-426.
- Baumgartner, T. A., & Jackson, A. S. (1991). Measurement for Evaluation in Physical Education and Exercise Science (4th ed.). Dubuque, IA: William C. Brown Publishers.
- Bergh, I., Kanstrup, I.-L., & Ekblom, B. (1976). Maximal oxygen uptake during exercise with various combinations of arm and leg work. Journal of Applied Physiology, 41, 191-196.
- Cummins, T. D., & Gladden, B. L. (1983). Responses to submaximal and maximal arm cycling above, at, and below heart level. Medicine and Science in Sports and Exercise, 15, 295-298.
- Egger, K. C., & Finch, A. E. (1988). Prediction of maximal oxygen intake using submaximal arm ergometry. The Journal of Sports Medicine and Physical Fitness, 28, 354-359.

- Franklin, B. A. (1985). Exercise testing, training and arm ergometry. Sportsmedicine, 2, 100-119.
- Franklin, B. A., Vander, L., Wrisely, D., & Rubenfire, M. (1983). Aerobic requirements of arm ergometry: implications for exercise testing and training. The Physician and Sportsmedicine, 11, 82-90.
- Glaser, R. M., Sawka, M. N., Brune, M. F., & Wilde, S. W. (1980). Physiological responses to maximal effort wheelchair and arm crank ergometry. Journal of Applied Physiology, 48, 1060-1064.
- Golding, L. A., Meyers, C. R., & Sinning, W. E. (Eds.) (1982). The Y's Way to Physical Fitness: The Complete Guide to Fitness Testing and Instruction. Rosemont, IL: YMCA of America.
- Jessup, G. T., Riggs, C. E., Lambert, J., & Miller, W. D. (1977). The effect of pedalling speed on the validity of the Astrand-Ryhming aerobic work capacity test. Journal of Sportsmedicine, 17, 367-371.
- Keyser, R. E., Mor, D., & Andres, F. F. (1989). Cardiovascular responses and anaerobic threshold for bicycle and arm ergometer exercise. Archives of Physical Medicine Rehabilitation, 70, 687-691.
- Lazarus, B., Cullinane, E., & Thompson, P. D. (1981). Comparison of the results and reproducibility of arm and leg exercise tests in men with angina pectoris. The American Journal of Cardiology, 47, 1075-1079.
- Magel, J. R., McCardle, W. D., Toner, M., & Delio, D. J. (1978). Metabolic and cardiovascular adjustment to arm training. Journal of Applied Physiology, 45, 75-79.
- McCardle, W. D., Katch, F. I., & Katch, V. L. (1991). Exercise Physiology: Energy, Nutrition, and Human Performance (3rd ed.). Philadelphia: Lea & Febiger.

- Miles, D. S., Cox, M. H., & Bomze J. P. (1989). Cardiovascular responses to upper body exercise in normals and cardiac patients. Medicine and Science in Sports and Exercise, 21, S126-S131.
- Pendergast, D. R. (1989). Cardiovascular, respiratory and metabolic responses to upper body exercise. Medicine and Science in Sports and Exercise, 21, S121-S125.
- Reybrouck, T., Heigenhauser, G. F., & Faulkner, J. A. (1975). Limitations to maximum oxygen uptake in arm, leg, and combined arm-leg ergometry. Journal of Applied Physiology, 38, 774-779.
- Rowell, L. B., Taylor, H. L., & Wang, Y. (1964). Limitations to prediction of maximal oxygen intake. Journal of Applied Physiology, 19, 919-927.
- Sawka, M. N. (1986). Physiology of upper body exercise. Exercise and Sports Sciences Reviews, 14, 175-211.
- Sawka, M. N., Foley, M. E., Pimental, N. A., Toner, M. M., & Pandolf, K. B. (1983). Determination of maximal aerobic power during upper body exercise. Journal of Applied Physiology, 54, 113-117.
- Toner, M. M., Sawka, M. N., Levine, L., & Pandolf, K. B. (1985). Cardiorespiratory responses to exercise distributed between the upper and lower body. Journal of Applied Physiology, 54, 1403-1407.
- Vander, L. B., Franklin, B. A., Wrisley, D., & Rubenfire, M. (1984). Cardiorespiratory responses to arm and leg ergometry in women. The Physician and Sportsmedicine, 12, 101-107.
- Vokac, Z., Bell, H., Bautz-Holter, E., & Rodahl, K. (1975). Oxygen uptake/heart rate relationship in leg and arm exercise, sitting and standing. Journal of Applied Physiology, 39, 54-59.

Walker, R., Powers, S., & Stuart, M. K. (1986). Peak oxygen uptake in arm ergometry: effects of testing protocol. British Journal of Sports Medicine, 20, 25-26.

Zwiren, L. D., Freedson, P. S., Ward, A., Wilke, S., & Rippe, J. M. (1991). Estimation of VO_2 max: A comparative analysis of five exercise tests. Research Quarterly for Exercise and Sport, 62, 73-78.

APPENDIX A
STUDY TO INVESTIGATE THE RELIABILITY OF A SUBMAXIMAL
ARM ERGOMETRY PROTOCOL TO DETERMINE MAXIMAL
OXYGEN UPTAKE IN UPPER BODY EXERCISE

STATEMENT OF INFORMED CONSENT– FOR MAXIMAL AND SUBMAXIMAL
ARM ERGOMETRY TESTING

Invitation to Participate

You are invited to participate in a study investigating the reliability of a submaximal arm ergometry test as used to predict maximal oxygen consumption for upper body exercise. This study will be conducted at the San Jose State University campus.

Basis for Selection

You have been selected as a participant because you are a healthy male or female aged 18 to 40 years. Should you decide to participate, your response to a health history questionnaire will be reviewed by an exercise physiologist and, if satisfactory, you will be asked to participate in the tests described below.

Purpose of the Study

The purpose of this study is to investigate the reliability of a submaximal arm ergometry test as used to predict maximal oxygen consumption for upper body exercise.

subject's initials_____ investigator_____

Explanation of ProceduresArm Cranking Test (approximately 45 minutes)

This testing session will be used to determine your submaximal and maximal oxygen consumption capabilities for upper body exercise by pedalling a cycle ergometer with your arms only at progressively increasing levels of resistance. Your expired air will be collected through a mouthpiece connected to rubber tubing. Your heart rate will be monitored by five electrodes attached to your chest wall. The initial resistance for the cycle ergometer will be set at zero, at a pedal rate of 50 RPM, for the first minute to become accustomed to pedalling the arm ergometer. After the warmup period the first workload will be set at 150 kpm for a two minute period. If your heart rate is less than 100 beats per minute at the end of the first workload the second workload will be increased by 150 kpm, if your heart rate is greater than 100 bpm the workload will be increased by 75 kpm. After your heart rate has passed 100 bpm the workload will be increased by 75 kpm every two minutes. When your heart rate reaches a point between 60-70% of your predicted maximal heart rate, an additional one to two minutes may be required at that workload to achieve a steady state heart rate. After you have achieved a steady state heart rate between 60-70% of your predicted maximum the workload will be increased by 75 kpm every minute. The test will end when you indicate that you no longer wish to continue or your responses (heart function, respiration and/or physical appearance) indicate that you should not continue or have reached your maximal effort. Following completion of this test, the resistance will be reduced so that you can recover comfortably.

subject's initials _____ investigator _____

Possible Discomforts

Some discomfort and dryness of the mouth, throat and chest as a result of restricted breathing may occur. You may feel lightheaded, fatigued and slightly nauseous for a short period of time following the tests. Also, you may experience the discomforts commonly associated with exercise: sweating, increased heart rate, increased breathing rate and elevated body temperature. At or near maximal exercise you may experience abnormal blood pressure, fainting and/or dizziness, muscle fatigue or cramps and abnormalities in heart beat. If abnormalities are detected in electrocardiograph recordings, you will be excluded from this investigation.

Benefits from participation in Study

You will benefit from this study by receiving feedback on your cardiorespiratory endurance characteristics for upper body exercise.

Assurance of Confidentiality

Each subject's data will be coded by number, not subject name, to ensure maximum confidentiality. The results of this investigation may be used for research publication and presentation. Your right to confidentiality will be protected unless your express consent is granted prior to the publication or presentation of the data.

Withdrawal from the Study

You may withdraw your consent and discontinue your participation in this study at any time (including during the testing) without prejudice. You may also decline to answer any question or item on the health history questionnaire.

Testing will be supervised and conducted by Dr. Craig J. Cisar,

subject's initials_____ investigator_____

Certified Exercise Test Technologist and Greg Asplund a graduate student. Certified CPR personnel will also be present during the testing.

If you have any questions about the investigation now or during the testing, please feel free to ask. If additional questions come up later or in the case of an emergency, Greg Asplund (408) 927-0989, Dr. Craig J. Cisar (408) 924-3018 will be happy to answer them. Complaints about the research may be presented to Dr. James Bryant, Chairman of the Department of Human Performance, at (408) 924-3013. Questions or complaints about the research, subjects', or research related injury may be presented to Serena Stanford, PhD., Associate Academic Vice President of Graduate Studies and Research, at (408) 924-2480.

Consent

By signing this form, you are agreeing that:

- (a) you have decided to participate in this study having read the information provided above;
- (b) you understand the discomforts and risks involved;
- (c) you understand that you can withdraw at any time; and
- (d) you understand that your name will be kept confidential except with your express consent.

SIGNATURE _____ DATE _____

PRINT NAME _____

SIGNATURE OF WITNESS _____

SIGNATURE OF INVESTIGATOR _____

This medical history form is for research to be performed in the Department of Human Performance of San Jose State University. All information will be kept confidential. The information will be used in evaluating your health and ability to perform the tests to be used in research. Please make this record as accurate and complete as possible, yet free of meaningless detail. Please fill out this form carefully and thoroughly. Then check it over to be sure you have left nothing out.

Name _____ Age _____ Sex _____ Date _____

Height _____ Weight _____ Phone #: Home: (____) _____ Work: (____) _____

Address _____

Personal Physician (Local): _____

Address: _____

Phone Number: (____) _____

Person to Contact in Case of an
Emergency: _____

Address: _____

Relationship to you: _____

Phone Number: Home: (____) _____ Work: (____) _____

MEDICAL (Check if yes)

Past History: In the past have you ever had:

☐ Heart Attack/Stroke
When?	☐ Allergic reactions
Explain:
☐ Rheumatic Fever	☐ Tuberculosis
☐ Heart Murmur	☐ Bronchitis
☐ Heart Trouble:	☐ Asthma
☐ Heart Surgery	☐ Arthritis of legs or arms
☐ Rhythm abnormalities	☐ Abnormal chest X-ray
☐ High Blood Pressure	☐ Dizziness or fainting spells
☐ Disease of Arteries	☐ Scarlet fever
☐ Varicose Veins	☐ Anemia
☐ Lung Disease	☐ Thyroid problems
☐ Injuries to back,
knees or ankles	☐ Urinary tract infections, kidney
stones, prostate problems
☐ Epilepsy or convulsions	☐ Elevated cholesterol
☐ Diabetes or abnormal
blood sugar test	☐ Hernias
	☐ None of the above

Family History: Have any blood relatives had? (include parents, sisters, brothers, aunts, uncles, and grandparents)

☐ Heart attacks under age 50	☐ Diabetes
☐ Strokes under age 50	☐ Congenital heart disease
☐ Heart operations	☐ Asthma or hay fever
☐ High blood pressure	☐ Obesity
☐ High cholesterol	☐ None of the above

Present Symptoms: Have you recently (in the past 6 months) had?

☐ Chest pain or pressure	☐ Arthritis
☐ Shortness of breath	☐ Swollen legs
☐ Heart palpitations	☐ Awakened short of breath
☐ Light headedness	☐ Loss of consciousness
☐ Cough on exertion	☐ Joint soreness
☐ Coughing up blood	☐ Chronic muscle soreness
☐ Back pain	☐ None of the above

List any prescribed medication you are now taking.

List any self-prescribed medication or diet supplements you now take.

Date of last complete physical exam: month_____ year_____ () can't remember
 results were: () normal () abnormal

Date of last chest X-ray: month_____ year_____ () can't remember
 results were: () normal () abnormal

Date of last electrocardiogram (ECG): month_____ year_____ () can't remember
 results were: () normal () abnormal

Have you ever had any major chronic skeletal or muscular injuries? () yes () no
 If yes, explain:

List hospitalization including dates and reasons for hospitalization:

List any allergies (including drug allergies):

EXPLAIN ANY OTHER SIGNIFICANT MEDICAL PROBLEM THAT YOU CONSIDER IMPORTANT FOR US TO KNOW.

EXERCISE

Are you currently involved in a regular exercise program? () yes () no

If yes:

what kind of activity?

how often (duration & # of days per week)?

Do you regularly walk or run one or more miles continuously? () yes () no

If yes, average number of miles you cover per workout or day: _____

What is your average time per mile? _____ minutes () don't know

Do you regularly swim, bicycle or participate in other aerobic exercise? () yes () no

If yes, which activities? _____

Do you frequently participate in competitive sports? () yes () no

If yes, which one or ones? _____

HEALTH

How would you describe your general health?

() poor () fair () average () good () excellent

Have you ever been advised by a physician not to exercise because of a medical problem?

() yes () no If yes, explain:

I certify that, to the best of my knowledge, the foregoing answers are accurate and true.

 Signature

 Date