THE EFFECT OF SUPINE AND UPRIGHT POSITIONS ON THE HEMODYNAMIC AND METABOLIC PERFORMANCE OF BICYCLE EXERCISE

A Thesis Presented

to

The Graduate Faculty

University of Wisconsin-La Crosse

In Partial Fulfillment

of the Requirements for the

Master of Science Degree

---

by

Daniel R. Timmons

August, 1981

ABSTRACT

TIMMONS, Daniel R. The effect of supine and upright positions on the hemodynamic and metabolic performance of bicycle exercise. M.S. in Adult Fitness/Cardiac Rehabilitation, 1981. 84 p. (Dr. Glen Porter).

Sixteen male college students ($\overline{X}$ = 21.5) completed both a submaximal upright and supine bicycle exercise protocol. Progressive workloads of 200, 400, 600, and 800 KPM were completed twice by each subject for each test condition. The order of testing was randomized so that half of the subjects performed first in the upright position, while the remaining half performed first in the supine position. The pedal speed, exercise protocol, and ergometer were identical for each test. Oxygen consumption (VO2 ml/min), heart rate (HR), systolic blood pressure (SBP), and rating of perceived exertion (RPE) were determined during the third minute of each workload. Results indicated significantly lower mean values for oxygen consumption ($p < .001$) and HR ($p < .02$) when exercising in the supine position. A significantly higher RPE ($p < .05$) value was found for the last two workloads in the supine position. No significant differences ($p > .05$) were found between SBP, when comparing upright and supine bicycle exercise. No significant differences were found between any test-retest variables for VO2, HR or SBP. The mean RPE value for T2 was found to be significantly lower than the T1 value. These data indicated that there were statistically significant metabolic, hemodynamic and perceived exertion differences between submaximal upright and supine bicycle exercise. The magnitude of these differences was quite small and would be of little importance in clinical evaluations.

UNIVERSITY OF WISCONSIN - LA CROSSE
School of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: Daniel R. Timmons

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

M.S. in Adult Fitness/Cardiac Rehabilitation

The candidate has completed his/her oral report.

Glen Porter	5-5-81
Thesis Committee Chairperson	Date
Donald R. Kendall	5/6/81
Thesis Committee Member	Date
Keith A. Kemper	5-6-81
Thesis Committee Member	Date

This thesis is approved for the School of Health, Physical Education and Recreation.

Glenn M. Smith	5-7-81
Dean, School of Health, Physical Education and Recreation	Date

ACKNOWLEDGEMENTS

I would like to thank my thesis committee members Dr. Glen Porter, Dr. Don Kirkendall, and Dr. Keith Kensinger for their continued support, assistance and input in this project. I would like to thank my mother and father for their continued interest and support throughout my graduate work. Another thanks to the AFCR class of 1980 and 1981, we couldn't have made it without each other.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	Need for the Study	4
	Purpose	5
	Null Hypotheses	6
	Assumptions	6
	Delimitations	7
	Definition of Terms	7
II.	REVIEW OF THE RELATED LITERATURE	9
	Introduction	9
	A Comparison of Supine and Upright Bicycle Ergometry . . .	10
	Summary of Upright and Supine Bicycle Ergometry	14
	The Metabolic Cost of Upright Bicycle Ergometry	16
	Summary of Upright Bicycle Ergometry Studies	23
	Conclusions	26
III.	METHODS	27
	Subjects	27
	Testing Procedures	27
	The Testing Bicycle Ergometer and Protocol	29
	Data Collection	30
	Experimental Design and Statistical Analysis	33
IV.	RESULTS	35
	Oxygen Consumption (ml/min)	35

CHAPTER PAGE

Oxygen Consumption (Linear Regression Equation) 37

Heart Rate 40

Systolic Blood Pressure 40

Rating of Perceived Exertion 42

Hip Angle Measurements 45

V. DISCUSSION 46

Oxygen Consumption (ml/min) 46

Oxygen Consumption (Linear Regression Equation) 47

Heart Rate 50

Systolic Blood Pressure 51

Rating of Perceived Exertion 51

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 53

Summary 53

Conclusions 54

Recommendations 55

REFERENCES CITED 57

APPENDIX

A. PRE-EXERCISE MEDICAL HISTORY FORM 62

B. INFORMED CONSENT FORM 64

C. INSTRUCTIONS FOR PERCEIVED EXERTION 66

D. SUPINE AND UPRIGHT BICYCLE PROTOCOL 68

E. THE UPRIGHT BICYCLE ERGOMETER 70

F. THE SUPINE BICYCLE ERGOMETER 72

G. CORRECTION FACTOR FOR THE DRY GAS METER 74

H. THE DETERMINATION OF VO_2 76

APPENDIX PAGE

I. HIP ANGLE MEASUREMENTS 79

J. ANALYSIS OF VARIANCE TABLES 81

CHAPTER I

INTRODUCTION

Exercise electrocardiography (ExEKG) has become one of the most important and most popular non-invasive tests in the field of cardiovascular disease (Chung, 1979; Kattus, 1975). Similarly, exercise radionuclide studies (ExRNUC) of cardiac performance are playing an increasing role in the diagnosis and evaluation of cardiac abnormalities (Reduto & Zaret, 1979).

Initially, ExEKG tests were conducted by exercise physiologists to determine the performance characteristics of athletes during exercise. In addition, physicians began using ExEKG as a diagnostic testing modality for the detection of ischemic heart disease. However, in recent years the indications for exercise testing have been broadened. The application of ExEKG to many more clinical situations has increased as equipment has improved and as knowledge in the area has grown. At present, the usual clinical indications for an ExEKG test include (Naughton & Haider, 1973; Chung, 1979):

1. The diagnosis of the etiology of undefined chest pain.

2. The evaluation of an individual's functional capacity for work and/or play.

3. The evaluation of a patient's response either to surgical, pharmacological, or rehabilative therapy.

Exercise radionuclide studies offer additional information in the diagnosis and evaluation of cardiac patients. First pass radionuclide angiography and gated cardiac blood pool imaging are two common radionuclide studies (Allen, 1977) which can be performed during physical exercise. Exercise during cardiac catheterization has also been performed as an invasive technique for the evaluation of cardiovascular performance (Bevegard, Holmgren & Jonsson, 1960; Bevegard, 1963; Granath, Jonsson & Strandell, 1964).

The information obtained from radionuclide studies can offer the physician information about coronary anatomy, heart volume, segmental wall motion, and left ventricular function. Exercise performed during the radionuclide evaluation provides information on the functional ability or disability of the patient. In the patient with coronary artery disease (CAD) the performance of physiologic stress such as exercise has been shown to elicit abnormalities in ventricular performance that are not present at rest (Reduto & Zaret, 1979). The evaluation of total and regional ventricular performance during exercise has been demonstrated as a highly sensitive method for the non-invasive detection of CAD (Borer, Bacharach, Green, Kent & Johnston, 1978; Borkowski, Berger, Langou, Cohen, Gottschalk & Zaret, 1977; Berger, Reduto, Johnston, Borkowski, Sands, Cohen, Langou, Gottschalk & Zaret, 1979). Thus, the ExRNUC techniques provide an additional non-invasive means of assessing the presence of cardiovascular disease and/or ventricular function.

Several problems arise when ExRNUC techniques are applied during physical exercise. One problem encountered in completing the evaluation is that a good deal of body movement may result during the exercise. Because of the need for minimal movement and exact equipment location during the radionuclide study, a supine position is often utilized during the procedure. With the patient in the supine position on a flat surface, a bicycle ergometer can be pedaled with minimal body movement. Special supine exercise tables with bicycle ergometers are now available for this purpose (Quinton, 1979).

The determination of functional work capacity is an important consideration in the assessment of individuals with CAD. Functional work capacity is typically represented by the amount of oxygen consumed per minute (VO_2). It can be expressed in milliliters of oxygen per kilogram of body weight (ml/kg/min), liters per minute (L/min), or any variation of this form. The American Heart Association (1978) defines functional work capacity as one of four MET classifications or functional classes (one MET is equal the approximate resting oxygen consumption or 3.5 ml/kg/min).

To directly measure VO_2, several methods of open circuit techniques are available (Consloazio, Johnson & Pecora, 1963). These direct measurements of VO_2 are costly and time consuming. The prediction or estimation of VO_2 from exercise intensities of walking, running, and bicycling (American College of Sports Medicine, 1975; Dill, 1965; Margaria, 1963; Nagle, Balke & Naughton, 1965; Pugh, 1974) are more often used. Naughton and Haider (1973) and Fox, Naughton, and Haskell (1971) have shown the oxygen requirement of 1 kilopondmeter (KPM) of work on the bicycle to be approximately 2.0 ml/min. Balke (1960) suggests the constant of 1.8 ml/min to be equivalent to 1 kilogrameter (KGM) during any activity.

These assessments of the energy cost of bicycle work were performed with the subjects in the upright position. The question arises whether the energy cost of supine bicycle work is similar to exercise performed in the upright position.

Need for the Study

Exercise during radionuclide studies has been shown to be an important tool in the diagnosis and functional evaluation of the cardiac patient (Reduto & Zaret, 1979). The functional capacity attained during the ExRNUC evaluation is a factor which often plays an important role in the final assessment. Therefore, accurate predictions of functional capacity should be available if direct measurement will not be utilized.

The American College of Sports Medicine (1975), Astrand and Rodahl (1977), Astrand (1974), Bobbert (1960), Balke (1960), and Fox, Naughton and Haskell (1971) have developed prediction equations for VO_2 based on the workload performed on the bicycle ergometer. These evaluations of work were performed in the upright pedaling position, while ExRNUC evaluations are often performed in the supine pedaling position. A search of the literature by this investigator revealed no information concerning the development of a prediction equation for work performed on the bicycle ergometer in the supine position.

Several studies (Bevegard, 1963; Bevegard, et al., 1960; Granath, et al., 1964; Holmgren & Ovenfors, 1960; Stenberg, Astrand, Ekblom, Royce & Saltin, 1967; Thadani & Parker, 1978) have shown significant differences in the hemodynamics during supine and upright bicycle exercise. The studies that evaluated VO_2 and exercise capacity during supine and upright bicycle exercise have shown conflicting results. Several factors directly related to VO_2 such as stroke volume (SV), cardiac output ($\dot{Q}$), and arterio-venous oxygen difference ($a\text{-}vO_2$) have been shown to change significantly with a change in body position during exercise. The results of these studies indicated that there was a possible difference between the VO_2 during supine as compared to upright bicycle exercise. If this is true, the exercise VO_2 values for supine and upright bicycle exercise cannot be used interchangeably.

Larson (1974) suggested that there was a difference between supine and upright work and stated, "In supine exercise the efficiency is different and the normal upright VO_2 requirement relationship does not apply." Bygdeman and Wahren (1974) and Lecerof (1971) demonstrated that the exercise tolerance was lower in the supine position than in the upright position of subjects with CAD.

Therefore, there appears to be a need to evaluate bicycle exercise in both the supine and upright positions. Oxygen consumption (VO_2) should be evaluated to determine if a significant difference exists between the two positions. If a significant difference is found, prediction equations should be developed for exercise that is performed in the supine pedaling position.

Purpose

Therefore, the purpose of this study was two-fold. First, the present study was designed to compare the metabolic cost (Vo_2) of supine versus upright bicycle exercise. In an attempt to supplement the metabolic data, heart rate (HR), systolic blood pressure (SBP), and ratings of perceived exertion (RPE) were also evaluated. Secondly, linear regression equations were developed and compared to estimate the oxygen cost of exercise performed in the supine and upright pedaling positions.

Null Hypotheses

In this study several null hypotheses were tested. These null hypotheses were:

1. There was no significant difference between the mean oxygen consumptions at progressive workloads measured in the supine and upright positions.

2. There was no significant difference between the slope and Y-intercepts of the lines for work performed in the supine and upright positions.

3. There was no significant difference between the mean heart rates at progressive workloads when measured in the supine and upright positions.

4. There was no significant difference between the mean systolic blood pressures at progressive workloads when measured in the supine and upright positions.

5. There was no significant difference between the mean ratings of perceived exertion at progressive workloads when determined in the supine and upright positions.

Assumptions

The following were basic assumptions made for the purpose of this investigation:

1. It was assumed that the subjects followed the pretest instructions and did not eat, smoke, take medication, or participate in

vigorous physical activity within 4 hours prior to each test session.

2. It was assumed that no subject had any significant metabolic or pulmonary abnormalities.

3. It was assumed that the researcher and specific laboratory conditions had no adverse effect on the performance of the subjects.

4. It was assumed that the subjects were at a metabolic steady state during the expired gas collection period.

Delimitations

The following were delimitations of this investigation:

1. The subjects of this investigation were 16 male undergraduate students attending the University of Wisconsin at La Crosse.

2. The subjects were healthy consenting volunteers between the age of 20 and 22 years.

3. The subjects were limited to the performance of submaximal exercise.

4. The collection of data was limited to one set of values per exercise workload.

Definition of Terms

Exercise Electrocardiogram (ExEKG) - A record of the electrical activity of the heart taken during the performance of physical exercise.

Exercise Radionuclide Study (ExRNUC) - A technique of examining the function of the heart by means of radioactive material and x-ray equipment during the performance of physical exercise.

Heart Rate (HR) - The number of times the heart contracts per minute.

Kilopond Meter (KPM) - A unit of work performed when one kilogram is moved one meter against the force of gravity.

MET - An expression of oxygen consumption or energy expenditure. One MET is equal to 3.5 ml/kg/min of oxygen consumption.

Oxygen Consumption (VO_2) - The amount of oxygen taken in and utilized by the body per minute. Expressed in milliliters per minute (ml/min).

Rating of Perceived Exertion (RPE) - The total feelings of physical stress, effort, and fatigue expressed by an individual during physical exercise or work. In this study RPE was measured with the Borg Scale.

Systolic Blood Pressure (SBP) - The pressure recorded in the bracial artery during the ventricular contraction phase of the heart beat.

CHAPTER II

REVIEW OF THE RELATED LITERATURE

Introduction

During the last 10 years, ergometry has been applied within sport physiology, industry, and medicine. Consequently the bicycle ergometer has become an important tool in the evaluation of physical work capacity and performance.

Astrand (Varberg, Sweden, p. 9) stated the usefulness of the bicycle ergometer in the following manner:

> Bicycling has proven to be a very suitable work form, since, among other things, at a given load, (submaximal), it demands about the same energy output, whether the subject be young or old, trained or out of condition, elite bicyclist or unfamiliar with the sport. This instrument provides an exact measurement of the performed external work, and thus a graded and measurable load can be applied to the subject.

Even 30 years ago physiologists recognized several advantages of the bicycle ergometer. Wahlund (1948, p. 18) stated, "Bicycle ergometer work seems to be superior to almost any type of work for practical use." The following summary shows its advantages:

1. The bicycle ergometer has proven to be a practical apparatus for laboratory work, taking up small space, and being easy to handle.

2. The work has been found to be exactly reproducible.

3. A large number of muscles are involved.

4. Oxygen consumption has been reported to be directly related to workload and the mechanical efficiency determined on various individuals showed comparatively slight differences.

5. The bicycle has made possible direct comparisons between different subjects and between the reactions at different loads, as there were few extra movements not taking part in the production of the work output.

6. Various determinations were easily made during work.

Both Astrand and Wahlund stated that the oxygen consumption and workload were directly related. However, no mention was made of the effect that a supine position would have on this relationship.

This chapter consists of a review of the literature related to the relationship of several metabolic and hemodynamic factors in the supine and upright positions. The chapter will be broken into two sections. In the first section, factors such as Vo_2, HR, SBP, and RPE will be discussed. The results of a-vO_2, SV, and $\dot{Q}$ also are reviewed in the second section when performed in both the supine and upright positions because of their direct effect on VO_2. The second section will deal with the energy cost of bicycle exercise performed in the upright position by examining the prediction equations and tables for oxygen consumption based on workload.

A Comparison of Supine and Upright Bicycle Ergometry

Several studies have demonstrated significant differences in various hemodynamic and metabolic variables when comparing exercise in the supine and upright positions. The following studies were a review of the current literature and examined the results with special reference placed on VO_2, HR, SBP, and RPE. Stroke volume (SV), cardiac output ($\dot{Q}$), and arterio-venous oxygen difference (a-vO_2) were also reviewed because of the direct role they play in VO_2.

Bevegard, Holmgren and Jonsson (1960)

Ten healthy, adult, male subjects were studied during exercise on an electrically braked bicycle ergometer. Hemodynamic and metabolic data were calculated during two submaximal workloads. One workload was described as that which increased the HR to 150 beats per minute (PWC 150). The other workload was determined at a steady state prior to PWC 150. Identical workloads were performed in both the supine and upright positions.

The results of this study showed no significant difference in VO_2, HR, or SBP between the two positions at either workload. In the supine position, the SV and $\dot{Q}$ were significantly greater than when performed in the upright position, at both workloads. The $a\text{-}vO_2$ was significantly less in the supine position at both workloads when compared to the upright position.

Bevegard, Holmgren and Jonsson (1963)

Eight well-trained cyclists were evaluated on a bicycle ergometer at workloads of 800 and 1600 KPM. Hemodynamic and metabolic variables were determined in both the supine and upright positions. The results showed no significant difference in HR between the two positions. The VO_2 was significantly less (95 ml/min) in the supine position at 800 KPM, but no significant difference was seen at 1600 KPM. SBP was significantly higher in the supine position at a workload of 1600 KPM but showed no significant difference at the 800 KPM workload.

The $\dot{Q}$ was significantly greater in the supine position at both workloads. The SV was significantly greater in the supine position at a workload of 1600 KPM but not at the 800 KPM workload. The a-vO_2 was significantly less in the supine position at both workloads when compared to the upright values.

Granath, Jonsson and Strandell (1964)

Seventeen healthy male subjects, age 61 to 83 years, performed two workloads of the same intensity in both the supine and upright positions on a bicycle ergometer. The first workload was an average of 278 KPM and the second was approximately twice the first workload ($\overline{X}$ = 553 KPM). The results of the study showed no significant difference in HR or VO_2 between the two body positions at either workload. $\dot{Q}$ and SV increased significantly at both workloads in the supine position. The a-vO_2 was significantly less in the supine position when compared to the upright values.

Holmgren and Ovenfors (1960)

Ten healthy male athletes between the age of 17 and 18 years were studied on a bicycle ergometer during workloads of 300, 600, 900, 1200, and 1600 KPM. Two identical tests were performed, one in the supine position and the other in the upright position. The results showed a significantly lower HR in the supine position at 900 KPM. The other workloads showed no significant difference in the HR response between the two positions. The SV during each of the workloads was significantly higher in the supine position when compared to the upright position.

Thadani and Parker (1978)

Ten healthy sedentary men between the age of 32 and 58 were studied in the supine and upright positions on a bicycle ergometer. Pretest workloads that would induce mild fatigue with exercise in 4 to 6 minutes were determined for each subject. These workloads were recorded and used for the evaluation in the supine and upright positions. The results showed a significantly lower HR in the supine position with no significant difference seen in SBP between the two positions. There was a significantly greater SV in the supine position but no signficant difference seen in $\dot{Q}$.

Lecerof (1971)

Hemodynamic studies were performed on 37 male subjects between the age of 40 and 67 years. All the subjects had a history of chest pain on exertion. The exercise tests were performed on the same electrically braked bicycle ergometer at 2 identical workloads in both the supine and upright positions. The results of this study showed that at both workloads there were significantly higher HR values found in the supine position. No statistically significant differences were found in the SBP values between the supine and upright positions.

At the termination of the tests, due to maximal exercise levels, the workload was significantly greater in the upright position. HR and SBP at maximal levels were significantly higher in the upright position when compared to the supine position.

Stenberg, Astrand, Ekblom, Royce and Saltin (1967)

Four female and 6 male, well-trained subjects performed on a mechanically braked bicycle ergometer. Progressive workloads from 300 KPM to maximal values were performed in the supine and upright positions. Generally, the HR was lower in the supine position than in the upright at the same level of VO_2. In the supine position the VO_2 was generally lower on the heavier but still submaximal loads when compared to the upright position. On the lower loads, the $\dot{Q}$ was higher in the supine position than in the upright position. On the highest workload, the $\dot{Q}$ was slightly higher in the upright position. The $a\text{-}vO_2$ values were lower in the supine position when compared to the upright position.

Summary of Upright and Supine Bicycle Ergometry

The literature concerning upright versus supine bicycle ergometry has shown conflicting results in VO_2, HR, and SBP. These conflicting results could have partially been due to the methodological and statistical variation of each study. Different combinations of workloads ranging from 300 to 1600 KPM were utilized by each study. Several different types of bicycle ergometers and supine exercise tables were also used. There was general agreement in the literature concerning SV, $\dot{Q}$, and $a\text{-}vO_2$.

Oxygen Consumption (VO_2)

The literature showed conflicting results for VO_2 when comparisons were made between the supine and upright positions. Bevegard et al. (1960), Bevegard et al. (1963), and Granath et al. (1964) showed no significant difference in VO_2 between the two positions. Bevegard et al. (1963) and Stenberg et al. (1967) showed significantly lower values in the supine position when compared to the upright. All of these VO_2 values were obtained by the subjects during submaximal workloads.

Heart Rate (HR)

There were also conflicting results found for HR when comparisons were made in the supine and upright positions. Bevegard et al. (1960), Bevegard et al. (1963), Holmgren and Ovenfors (1960), and Granath et al. (1964) showed no significant difference between HR in the two positions. Holmgren et al. (1960), Thadani and Parker (1978), and Stenberg et al. (1967) showed a significant decrease in HR in the supine position when compared to the upright. All of the HR values were taken during submaximal workloads. Lecerof (1971) showed a significant increase in HR in the supine position with a cardiac population.

Systolic Blood Pressure (SBP)

Bevegard et al. (1960), Bevegard et al. (1963), Thadani (1978), and Lecerof (1971) showed no significant difference in SBP when comparisons were made between the supine and upright positions. Bevegard et al. (1963) showed significantly higher SBP values at the highest workload in the supine position when compared to the upright values. All of the SBP values were recorded during submaximal workloads.

Rating of Perceived Exertion (RPE)

No material could be found in the literature, by this investigator, comparing RPE values in the supine and upright positions. There was also no literature found dealing with RPE in the supine position alone.

Stroke Volume (SV)

Stroke volume was shown to increase significantly in the supine position when performing exercise on the bicycle ergometer. Bevegard et al. (1960), Granath et al. (1964), Holmgren and Ovenfors (1960), Thadani and Parker (1978), and Stenberg et al. (1967) showed significantly higher SV's in all instances. Bevegard et al. (1963) showed a significantly higher SV at a workload of 1600 KPM but no significant difference at 800 KPM. All of these studies were performed at submaximal exercise intensities.

Cardiac Output ($\dot{Q}$)

Bevegard et al. (1960), Bevegard et al. (1963), Granath et al. (1964) and Stenberg et al. (1967) showed significantly greater $\dot{Q}$'s in the supine position when compared to the upright position. Thadani and Parker (1978) showed no significant difference in $\dot{Q}$ between the two positions. Each of these studies were performed at submaximal levels.

Arterio-Venous Oxygen Difference ($a\text{-}vO_2$)

The determination of $a\text{-}vO_2$ was performed in 4 studies (Bevegard et al. 1960; Bevegard et al. 1963; Granath et al. 1964; Stenberg et al. 1967). All studies showed a significantly smaller $a\text{-}vO_2$ in the supine position when compared to the upright position. These studies were all performed at submaximal levels of exercise.

The Metabolic Cost of Upright Bicycle Ergometry

Several publications presented the metabolic cost of bicycle ergometric exercise to have a linear relationship to workload (Astrand & Rodahl, 1977; Balke, 1960; Bobbert, 1960; Fox, Naughton & Haskell, 1971; Naughton, 1973; Wahlund, 1948). The linear regression equations reviewed for O_2 consumption from workload were found to be slightly different and require a review. Where the data permitted, the relationship of workload to VO_2 was presented as a linear regression equation of the form $Y = a + bX$ (Brown & Hollander, 1977), where Y represented the VO_2 of the activity, X represented the workload in KPM, a represented the y-intercept, and b the slope of the line.

Fox, Naughton and Haskell (1971)

Fox et al. (1971) presented a table which represented the VO_2 requirements of bicycle ergometric workloads (Table 1).

Table 1

Predicted VO_2 from Workloads of 150 to 1800 KPM (Fox et al. 1971)

Workload (KPM)	150	300	450	600	750	900	1050	1200	1500	1800
VO_2 (ml)	600	900	1200	1500	1800	2100	2400	2700	3300	3900

Table 1 was designed for persons who could produce the workloads without having to exert themselves maximally. A linear regression equation of $Y = 300 + 2.0X$ was calculated using the data presented in Table 1. The authors did not give the details of the research that produced these results.

The work presented by Fox et al. (1971) has been cited by many of the current texts on exercise stress testing (American Heart Association, 1971; American Heart Association, 1973; Chung, 1979; Ellstad, 1975). The American College of Sports Medicine (1975) also used the material by Fox et al. (1971) as their reference when they recommended Fox's equation to predict VO_2 from workloads on the bicycle ergometer.

Astrand and Rodahl (1977)

Astrand and Rodahl (1977) offer a table that predicts VO_2 from workload (Table 2). This table was comprised from previous work done by Astrand, I., (1958), Astrand, I., (1960), Astrand, P., (1952), and Rhyming (1954).

Astrand and Rodahl (1977) did not present a prediction equation with Table 2. But, using their data, the regression equation of $Y = 100 + 2.3X$ was calculated.

Table 2

Predicted VO_2 from Workloads of 300 to 2400 KPM (Astrand & Rodahl, 1977)

Workload (KPM)	300	600	900	1200	1500	1800	2100	2400
VO_2 (ml)	900	1500	2100	2800	3500	4200	5000	5700

The data of Table 2 is dependent on the studies of several authors, a review of which follows. It is the combined results of work done over a period of several years and which included male and female subjects of various age and skill levels.

Astrand, I. (1958) used 81 male subjects between the age of 50 and 64 years. The work tests were performed on a Krogh bicycle ergometer. The objective of the tests were for each subject to perform two times with a workload of 615 KPM, and one or two times with 917 KPM. There was a 4 minute rest period between each workload. Using the mean VO_2 from the two workloads at each age category, a VO_2 prediction equation of $Y = 361 + 2.0X$ was calculated for the group.

Astrand, I. (1960) used 44 female subjects between the age of 20 and 65 years. The subjects performed on a Krogh bicycle ergometer with a pedal frequency of 50 RPM. The workloads began at 300 KPM and increased by 150 KPM until a maximal load was attained. The results revealed a rectilinear relationship between workload and VO_2. Using the mean VO_2 at each workload for each age group presented, the equation for VO_2 from workload was Y = 218 + 2.1X.

Astrand, P. (1952) used 21 male subjects and 31 female subjects. The male subjects performed workloads of 900, 1200, and 1500 KPM while the female subjects used workloads of 600 and 900 KPM. The pedaling rate was set at 50 RPM. The results indicated that the VO_2 increased linearly with increased intensities, and that the male and female subjects fit the same VO_2 curve. The linear regression equation of Y = 235 + 2.0X was calculated using the results of this study.

Rhyming (1954) used 29 male and 31 female subjects between the age of 20 and 30 years. The bicycle tests were performed on a Krogh bicycle ergometer with a pedal frequecy of 50 RPM. The male subjects performed at a workload of 900 KPM and the females at 600 KPM. The mean value for the male subjects at 900 KPM was 2110 ml/min and for the females at 600 KPM it was 1560 ml/min. The linear regression equation found for this group was Y = 140 + 2.2X.

Shephard (1973)

Shephard presented the results of the Astrand Nomegram (1960) and used two equations to derive VO_2 from workload. The prediction equations presented were different for male and female subjects. For men the equation was Y = 240 + 2.0X, and for women the equation was

Y = 200 + 2.0X. The methods used to derive these two formulas were not presented by the authors. This study was the only one found which used different formulas for male and female subjects.

Bobbert, A. (1960)

In this study, six male subjects between the age of 25 and 42 years performed on an electromagnetic resistance bicycle ergometer. The subjects were healthy, but not athletes and pedaled at a rate of 60 RPM. Workloads of 520, 704, 1010, and 1193 KPM were performed. Steady state was evaluated during the sixth minute of each workload. Both leg cycling and arm cranking were evaluated in this study. For leg cycling, the equation of Y = 333 + 2.1X was presented. Arm cranking was found to be of the same slope but higher in VO_2 per unit of work.

Bobbert reviewed the work of 7 other authors (Asmussen, 1939; Asmussen, 1947; Astrand, 1958; Christensen, 1931; Christensen, 1939; Muller, 1953; Nielsen, 1936) and combined the VO_2 determinations during various workloads and then calculated a prediction equation for leg cycling which was Y = 264 + 2.1X.

Strandell, T. (1964)

Nineteen healthy male subjects, age 61 to 83 years were exercised on an electrodynamically braked bicycle ergometer. The test started at a workload of 300 KPM and was increased every six minutes by 300 KPM until the subject was exhausted. The load at the maximal work intensity was represented by the heaviest load at which the subject worked for six minutes. The VO_2 in relation to workload at maximum work intensity was represented by the equation Y = 262 + 2.2X.

Wahlund (1948)

Four hundred and sixty-nine men were tested who ranged in age from 19 to 66 years. All subjects were referred for the test evaluation by a medical clinic and included a variety of subjects with pulmonary and cardiovascular abnormalities. The study also included evaluations of healthy men and athletes. Each subject performed on a Krogh bicycle ergometer at a rate of 60 RPM. Workloads ranging from 300 KPM to 1500 KPM were evaluated. VO_2 was recorded during each workload on all subjects. An analysis of variance performed on the test results of the subjects attaining a steady state revealed no significant difference among the groups.

The study concluded that, provided the person tested was not at the point of exhaustion, it was possible to get an estimate of VO_2 at the different loads without a special determination of expired gases. It was reported that the VO_2 was indirectly estimated from workload within a range of 8 percent in two-thirds of the cases. Using the raw data presented by Wahlund, the following linear regressions were computed for each of the 16 subgroups:

1. Subjects with valvular disease of the heart

$Y = 267 + 1.76X$

2. Subjects with congenital disease of the heart

$Y = 333 + 1.74X$

3. Subjects with suspected congenital disease of the heart

$Y = 408 + 1.60X$

4. Subjects suspected of rheumatic valvular disease of the heart

$Y = 386 + 1.67X$

5. Subjects with hypertension

$Y = 333 + 1.76X$

6. Subjects with actual or suspected acute myocarditis

$Y = 372 + 1.71X$

7. Subjects with enlarged hearts

$Y = 493 + 1.58X$

8. Subjects with various EKG abnormalities

$Y = 216 + 1.86X$

9. Subjects with no objective signs of heart or lung disease

$Y = 399 + 1.65X$

10. Subjects with emphysema and signs of heart disease

$Y = 507 + 1.48X$

11. Subjects suspected of emphysema

$Y = 362 + 1.58X$

12. Subjects with emphysema

$Y = 408 + 1.54X$

13. Subjects with tracheo-bronchitis without emphysema

$Y = 417 + 1.62X$

14. Ordinary healthy subjects

$Y = 403 + 1.63X$

15. Athletes

$Y = 365 + 1.71X$

Using the mean of all the data presented by Wahlund, a regression equation of $Y = 377 + 1.7X$ was calculated. This gives a prediction equation which is a combination of all the groups.

Summary of Upright Bicycle Ergometry Studies

The VO_2 table presented by Fox et al. (1971) and the table presented by Astrand and Rodahl (1977) are the two most cited in the current literature (American College of Sports Medicine, 1975; American Heart Association, 1973; Chung, 1979; Ellstad, 1975). These tables are identical at workloads of 300, 600, and 900 KPM. Beyond a workload of 900 KPM, the Astrand prediction exceeds that of Fox et al. by a mean of 123 ml/min.

Table 3 presents a summary of the VO_2 consumption studies performed on the bicycle ergometer. A prediction for workloads from 150 KPM to 1800 KPM is shown. The only study that appeared to differ considerably from the others was the study by Wahlund (1948). Wahlund's prediction values increasingly varied from the mean of all the data by 8 percent at 600 KPM and 15 percent at 1800 KPM.

A prediction equation of $Y = 260 + 2.0X$ was computed from the values at each workload, derived from the prediction equations of the 12 authors. The mean value from this equation differed by less than 1 percent from the mean value presented by Fox et al. (1971).

Table 3

VO_2 Derived from Prediction Equations and Tables of Several Authors

Author KPM	150	300	450	600	750	900	1050	1200	1500	1800
Astrand, I. (1958) Y = 361 + 2.0X	o 661	o 961	o 1261	o 1561	o 1861	o 2161	o 2461	o 2761	o 3361	o 3961
Astrand, I. (1960) Y = 218 + 2.1X	o 533	* 900	* 1190	* 1500	* 1780	o 2108	o 2423	o 2738	o 3368	o 3998
Astrand, I. & Rhyming (1977) Y = 100 + 2.3X	o 450	* 900	* 1200	* 1500	o 1825	* 2100	o 2515	* 2800	* 3500	* 4200
Astrand, P. (1952) Y = 235 + 2.0X	o 542	o 850	o 1157	o 1465	o 1772	o 2080	o 2387	o 2695	o 3310	o 3925
Bobbert (1960) Y = 333 + 2.1X	+ 651	+ 969	+ 1287	+ 1605	+ 1923	+ 2241	+ 2559	+ 2877	+ 3513	+ 4149
Bobbert (1960) 7 Authors Y = 264 + 2.1X	+ 579	+ 894	+ 1209	+ 1524	+ 1839	+ 2154	+ 2469	+ 2784	+ 3414	+ 4044
Fox et al. (1971) Y = 300 + 2.0X	* 600	* 900	* 1200	* 1500	* 1800	* 2100	* 2400	* 2700	* 3300	* 3900
Rhyming (1954) Y = 140 + 2.2X	o 474	o 809	o 1144	* 1480	o 1812	* 2150	o 2482	o 2816	o 3485	o 4154
Shephard (1973) Y = 240 + 2.0X (Male)	+ 540	+ 840	+ 1140	+ 1440	+ 1740	+ 2040	+ 2340	+ 2640	+ 3240	+ 3840

Table 3

VO_2 Derived from Prediction Equations and Tables of Several Authors (Continued)

Author KPM	150	300	450	600	750	900	1050	1200	1500	1800
Shephard (1973) $Y = 200 + 2.0X$ (Female)	+ 500	+ 800	+ 1100	+ 1400	+ 1700	+ 2000	+ 2300	+ 2600	+ 3200	+ 3800
Strandell (1964) $Y = 262 + 2.2X$	+ 590	+ 919	+ 1247	+ 1576	+ 1904	+ 2233	+ 2561	+ 2890	+ 3547	+ 4204
Wahlund (1948) $Y = 377 + 1.7X$	o 626	o 875	o 1124	o 1373	o 1622	o 1871	o 2120	o 2369	o 2867	o 3365
12 Studies Combined $Y = 260 + 2.0X$	o 567	o 875	o 1182	o 1490	o 1797	o 2105	o 2412	o 2720	o 3335	o 3950

* Derived from Table

o Derived from Prediction Equation from Means

+ Derived from Prediction Equation Given

Conclusions

As a result of the review of literature, it was apparent that there was conflicting results concerning VO_2, HR and SBP. There was no literature found by this investigator concerning RPE. This investigator also found no literature which dealt with linear regression equations for work performed in the supine position.

From the data received, it was apparent that further studies concerning VO_2, HR, SBP and RPE should be performed in the supine and upright positions.

CHAPTER III

METHODS

This study was designed to compare the metabolic cost (VO_2), hemodynamics, and perceived exertion of supine versus upright bicycle exercise. The same bicycle ergometer was used in both positions with the workloads and pedaling rate remaining identical from one test to the next. VO_2, HR, SBP and RPE were determined and compared at workloads of 200, 400, 600 and 800 KPM.

Subjects

Sixteen male students, ages 20-22 years from the University of Wisconsin-La Crosse, served as subjects for this study. The subjects were chosen from three class sections of PE 302, Physiology of Exercise. In order to participate in the study, each student was required to complete a short medical history form (Appendix A) and an informed consent form (Appendix B). No student reported any metabolic abnormalities, pulmonary problems, use of medication, or indicated any contraindications to exercise participation (ACSM, 1980).

Testing Procedures

Each subject reported on four separate occasions to the human performance laboratory at the University of Wisconsin-La Crosse for evaluation. The order of testing was randomized so that each subject was assigned to one of two testing orders. Eight subjects performed the first two tests in the supine position, while the remaining eight performed first in the upright position.

The subjects reported to the laboratory after refraining from food, cigarettes, and physical activity for four hours prior to the test. The subjects entered the laboratory and changed into athletic shoes and shorts. Body weight was determined and recorded to the nearest one-fourth pound. The subjects then reclined on a table while standard electrodes were positioned on the skin. During the electrode placement, the subjects read an explanation of the Borg (1970) Perceived Exertion Scale (Appendix C).

Seat height and body position adjustments were made on the first test in each position immediately after the electrode placement. On the second test in each position, the seat height and body position were identical to the first test setting in each position.

The blood pressure cuff and mouthpiece for gas collection were positioned and worn throughout the entire evaluation. Data were collected during the third minute of a three-minute resting period while the subject was placed in the pedaling position. The first workload was immediately begun after the rest period. Each workload was three minutes in duration with all data collection during the third minute. Each new workload immediately followed the previous one with no interruption in pedaling rate. The workloads consisted of 200, 400, 600, and 800 KPM with a pedaling rate of 50 revolutions per minute (Appendix D).

Immediately after the last workload, the subject pedaled for another 2 minutes at 300 KPM as a cooldown period. The electrodes, blood pressure cuff and gas collection equipment were then removed, and each subject left the laboratory.

The Testing Bicycle Ergometer and Protocol

The same Monarch Weight Bicycle Ergometer (Varberg, Sweden) was used in both the supine and upright evaluations. The weights and weight tray were calibrated on a triple beam balance scale and were corrected to the nearest gram. Additional weights were constructed and calibrated so that all possible workloads could be attained at a pedaling rate of 50 RPM (Appendix D).

In both the supine and upright evaluations, the pedaling position was determined when the subject was at a distance which required a slight bend in the knee when the leg was in a down or extended pedal position (Astrand, Varberg, Sweden; Shennum & deVries, 1976). The seat height and supine adjustment position were recorded and used for the second evaluation in each of the body positions.

The bicycle pedaling rate was maintained at 50 RPM with the use of an electric metronome (Franz Mfg. Co., New Haven, Conn.). The metronome was calibrated with a digital clock (National Electronics Systems, Streamwood, Ill.). The metronome was set at 100 beats per minute, and the subject was asked to complete one-half revolution for each beat by having one foot in the down position for each beat of the metronome.

Straps to hold the subjects' feet on the pedal were worn for pedaling in all evaluations. The straps were placed over the subjects' feet and were firmly secured to the pedal.

The Upright Bicycle Ergometer

A Monarch Weight Ergometer was used in the upright pedaling evaluation. The subject was seated on the bike with his right hand resting on the handgrip and the left arm in a natural hanging position (Appendix E).

The Supine Bicycle Ergometer

The same Monarch Weight Ergometer was used in the supine position as in the upright evaluation. The bicycle was secured to an examining table so that the axle center was 28 centimeters above the table (Appendix F). An adjustable shoulder pad unit was designed so that the pedaling leg length could be maintained. The pedaling position kept the subject in the supine position against the shoulder pads with both arms laying flat on the table.

Data Collection

Oxygen Consumption (VO_2)

Expired gases were collected during the third minute of each three-minute stage. The subjects wore a plastic noseclip and an all plastic headset which held a Daniels type valve (W.E. Collins, Braintree, Mass.) and a plastic mouthpiece. Gas was exhaled through the out port of the Daniels valve into rubber hosing (1½ inch od.) which was 192 centimeters long. This hosing led to a three-way low turbulence "Y" valve (W.E. Collins, Braintree, Mass.). The expired gas could be channeled into a 200 liter meteorological collection balloon (W.E. Collins, Braintree, Mass.) or back into room air. There was a rubber tube 15 centimeters long (3/16 inch id.) located in the gas sample collection port of the "Y" valve. This tube was used for gas fraction determinations of the expired sample. The small tube included a hose clamp that could be opened and closed when needed.

The "Y" valve was opened for one minute during the collection period and then closed. The entire gas collection bag and unit was removed from the collection hose for analysis. The gas sample tube was attached to Beckman LB_2 and Om11 analyzers through rubber tubing which contained fresh Dririte ($CaSO_4$).

The gas sample was analyzed for a 30-second period at a flow rate of 1000 ml minute. During the gas analyses, the sample was thoroughly mixed by shaking the collection bag throughout the procedure. The analyzers were calibrated with Scholander analyzed gas prior to and after each test.

Gas volume was determined by a dry gas meter (W.E. Collins, Braintree, Mass.). The gas meter was calibrated with a Tissot Tank (W.E. Collins, Braintree, Mass.) prior to all data collection. A correction factor of .9945 was used to correct all volumes determined by the dry gas meter (Appendix G). The expired gas was drawn out of the meteorological balloon and through the dry gas meter by an electric pump (W.E. Collins, Braintree, Mass.). A thermometer was positioned at the inflow port to determine gas temperature. The "Y" valve was connected directly to the gas meter and the valve was opened when a gas volume was taken. The meteorological balloon was squeezed twice to assure that all the gas was removed from the balloon. A volume of 500 ml was added to the gas volume before any calculations were computed. This additional volume accounted for the volume loss during the gas (O_2 & CO_2) analysis. The barometric pressure was recorded on a scientific barometer (Princo Instruments, Southampton, Pa.) before each test.

Oxygen consumption was calculated on a HP 2000 computer programmed with formulas similar to those of Consloazio, Johnson and Pecora (1963), and Sinning (1975) for calculations based on expired gas samples (Appendix H).

Heart Rate

Heart rates were determined by counting the R to R interval of a standard EKG recorded during a 6 second period. Heart rates were recorded during the last 30 seconds of each stage of the protocol.

A three channel Viagraph Electrocardiograph Recorder (International Medical Corporation, Denver, Co.) was used to obtain all heart rates. The 4 limb leads were chosen for electrode placement and leads I, II, and III were recorded.

Systolic Blood Pressure

Systolic blood pressure was determined using a mercury-gravity sphygmomanometer and stethoscope. The compression cuff was placed one-inch above the anticubital fossa of the left arm in each subject. The pressure within the compression cuff indicated by the level of mercury at the moment the korotokoff sounds were first heard represented the systolic blood pressure. The subject's arm in both the supine and upright position was placed at the level of the heart for each evaluation. Systolic blood pressure was determined during the first 30 seconds of each collection period at each stage of the protocol.

Rating of Perceived Exertion

The rate of perceived exertion was recorded during the last 10 seconds of each stage of the protocol. Prior to each test, the subject read a typed explanation of perceived exertion (Appendix C) explaining the standard Borg Scale (1970). During the test the subjects pointed to the appropriate perceived exertion level on a chart which contained the Borg Scale.

Pedaling Position

The hip angle was measured in both body positions during both flexion and extension. All measurements were taken on the same day on the right side of the subject's body. Hip angle was determined by 3 landmarks designated on each subject. Angles were measured with a Goniometer from the lateral epicondyl through the greater trochanter to a point lateral from the lower sternal border to the mid axillary line (Appendix I).

Experimental Design and Statistical Analysis

Sixteen subjects were randomly assigned to one of two test orders. Eight subjects performed the first two tests in the supine position, while the remaining eight performed first in the upright position. Standard descriptive statistics were used to describe the subject population.

The raw data consisted of VO_2, HR, SBP, and RPE for each subject at 4 workloads during two supine and two upright evaluations. Hip angle measurements determined in the supine and upright position completed the raw data on each subject.

A three-factor analysis of variance with repeated measures, two levels on position and test number and four levels on workload, was used to test the null hypotheses. The positions were divided into upright and supine, test number was divided into test 1 and test 2 in each position, and workloads were divided into 200, 400, 600 and 800 KPM. The Biomedical Computer Program (University of California, 1977) was utilized in the data analysis. When a significant difference was found among the interaction of any test variable, the Tukey post-hoc test (Clarke & Clarke, 1972) was performed to locate the significant differences between the paired means. A paired t-test was used on data collected on hip angle measurements. The .05 level of significance was used to test all null hypotheses.

CHAPTER IV

RESULTS

This investigation was conducted to determine the differences in responses to exercises performed in the supine and upright positions. Selected metabolic, hemodynamic and perceived exertion variables were measured during four submaximal workloads in both positions. A total of four tests were performed by each subject, two tests were performed in the upright position and two tests were performed in the supine position. The order of testing was randomized so that half of the subjects performed first in the upright position, while the remaining half performed first in the supine position.

Standard descriptive statistical analysis was performed on the subject characteristics (Table 4). A three-factor analysis of variance for repeated measures, with two levels of position, two levels of test trials and four levels of workload, was used to test the null hypotheses. When a significant difference was found among the interaction of any test variable, the Tukey post-hoc test (Clarke & Clarke, 1972) was performed to locate the significant differences between the paired means. A paired t-test was used on data collected on hip angle measurements. The .05 level of significance was used to reject the null hypotheses.

Oxygen Consumption (VO_2)

The mean VO_2 was significantly less ($p < .001$) in the supine position as compared to the upright position (Appendix J). The mean of both

Table 4

Subject Characteristics

Variable	$\overline{X}$	S.D.	Range
Age (yrs)	21.5	0.6	20-22
Height (cm)	178.5	6.2	165-187
Weight (kg)	78.6	10.7	61.5-104

$\overline{X}$ = Mean

S.D. = Standard Deviation

supine exercise trials ($\overline{X}$ = 1323) was 76 ml/min less than the mean of both upright exercise trials ($\overline{X}$ = 1399 ml/min). The means and the standard deviations of both test trials in the supine and upright position at workloads of 200, 400, 600, and 800 are presented in Figure 1. A further evaluation of the test variables (Appendix J) revealed no significant difference between the VO_2 in test 1 and test 2, or among the interaction of position and test 1 or 2, position and workloads, test 1 or 2 and workloads or among position, test 1 or 2 and workloads. There was a significant difference in VO_2 between all workloads.

These data indicated that the VO_2 in the supine exercise position was significantly less than in the upright position. Consequently, null hypothesis 1 was rejected.

Oxygen Consumption (Linear Regression Equation)

The linear regression equation of $Y = 491 + 1.82X$ was computed using the VO_2 collected in both test trials in the upright position. In the supine position the equation $Y = 451 + 1.74X$ was computed for the two test trials (Figure 2).

No significant difference was found between the slopes (b values) of the two linear regression equations ($p > .05$). Consequently, hypothesis 2 was accepted. There was a significant difference ($p < .01$) found between the y-intercepts of the two linear regression equations. The supine position y-intercept was significantly less than the value in upright position.

Figure 1: Mean VO_2 (ml/min) Values by Workload and Position

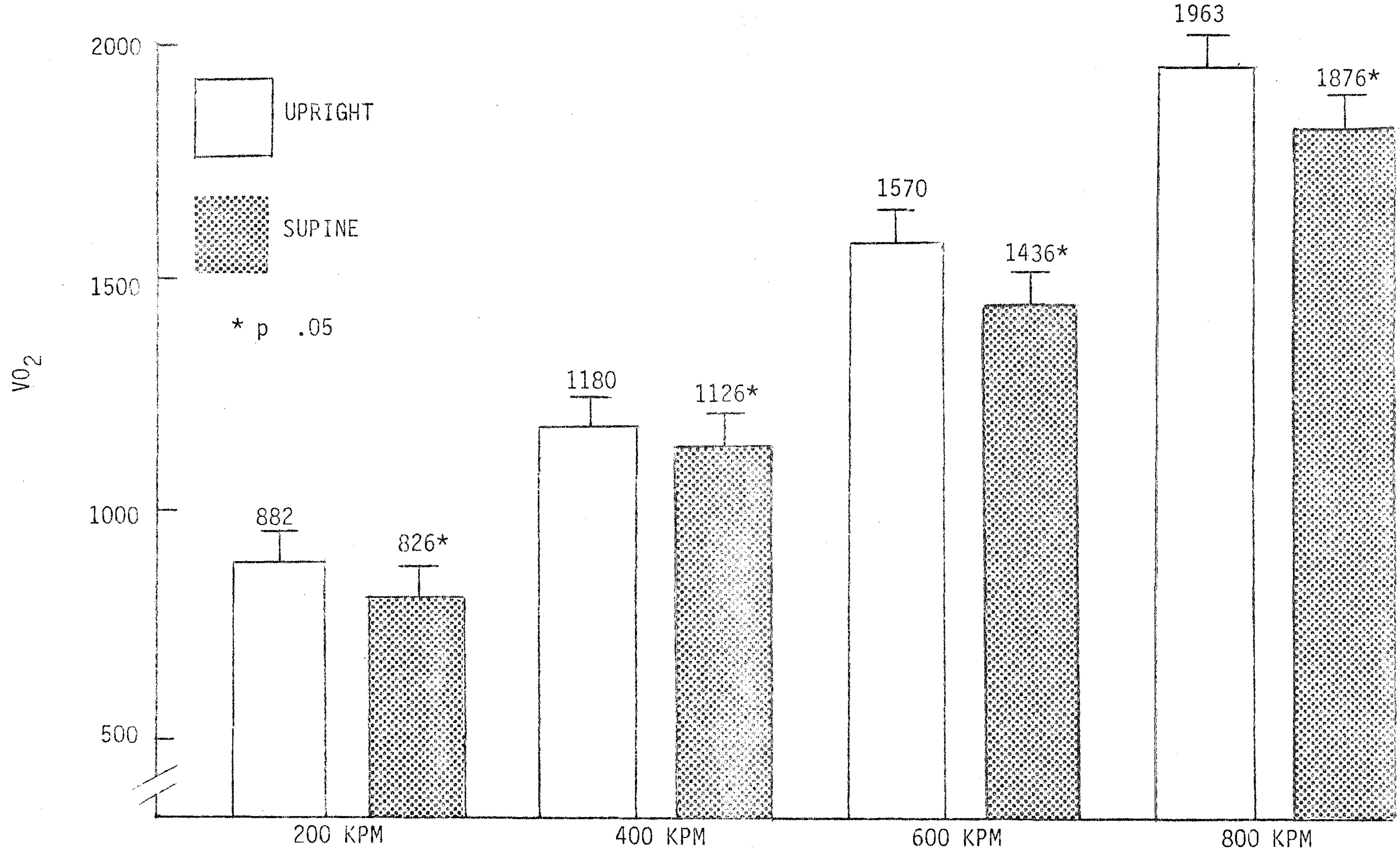
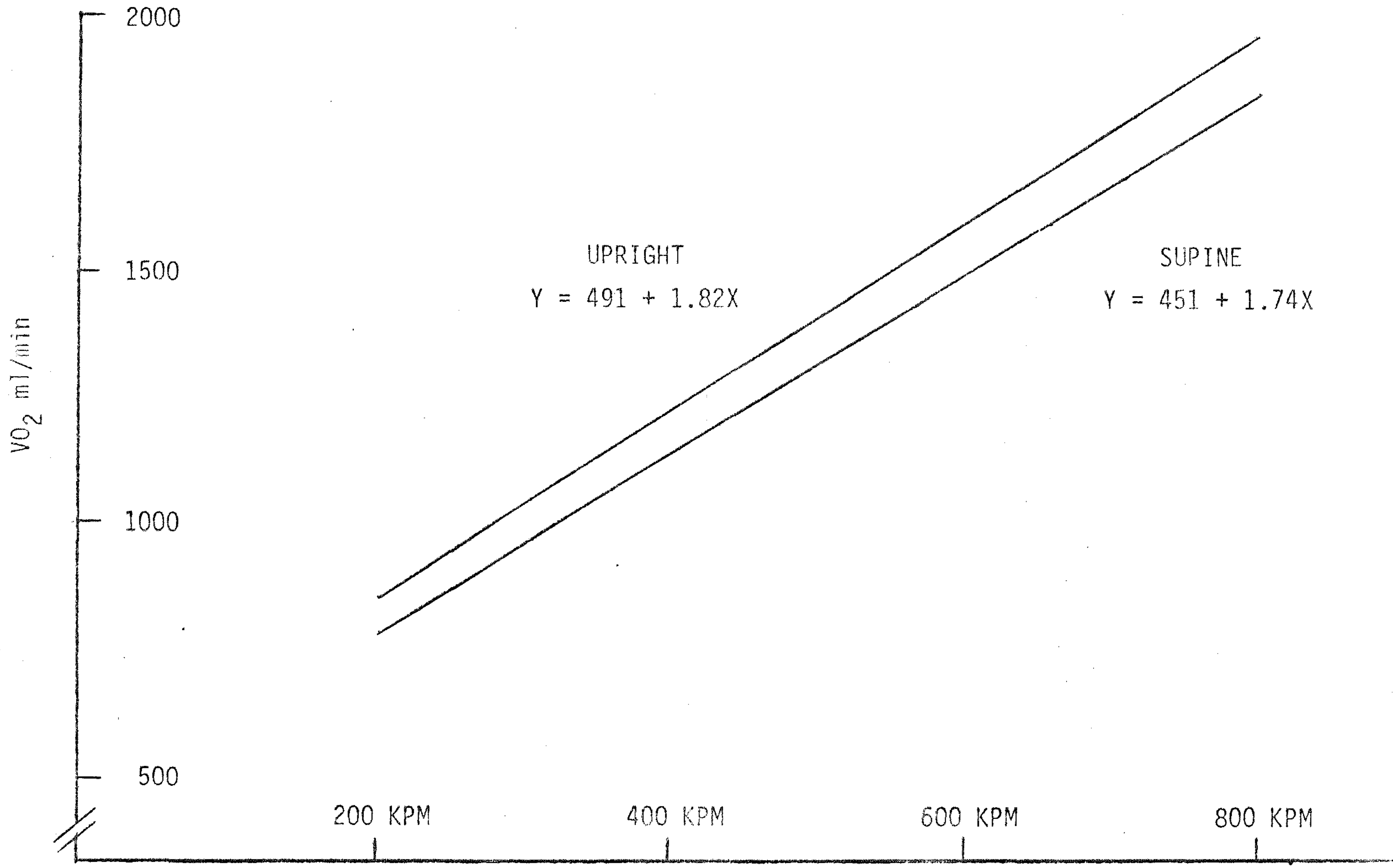


Figure 2: Supine and Upright Linear Regression Equations and Lines



Heart Rate (HR)

The mean HR was significantly less ($p < .02$) in the supine position when compared to the upright position (Appendix J). The mean HR of both supine exercise trials ($\overline{X}$ = 104) was five beats less than the mean HR of both upright exercise trials ($\overline{X}$ = 109). The means and standard deviations of both test trials in the supine and upright position at workloads of 200, 400, 600, and 800 KPM are presented in Figure 3.

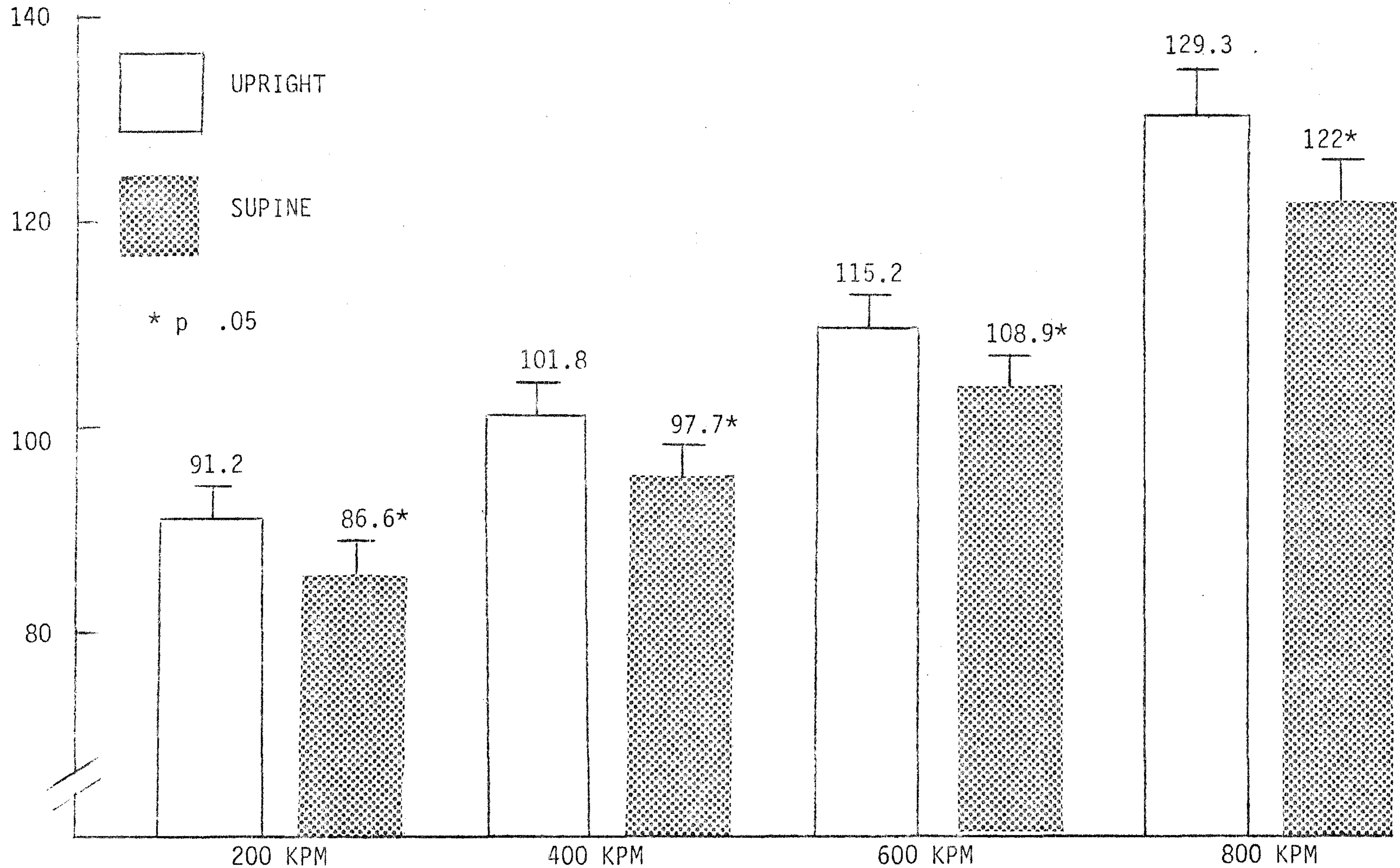
A further evaluation of the test variables (Appendix J) revealed no significant difference in HR between test 1 or test 2, or among the interaction of position and test 1 or 2, test 1 or 2 and workload, or among position, test 1 or 2 and workload. There was a significant difference revealed in HR between workloads, and among the interaction of position and workload (Appendix J). The Tukey post-hoc test performed on these data revealed no significant interaction in HR between position and workload. Thus, the no interaction statement was accepted between position and workload. The difference in the mean HR found between each workload was significantly different.

These data indicated that the mean HR in the supine exercise position was significantly less than the mean value found in the upright position. Consequently, null hypothesis 3 was rejected.

Systolic Blood Pressure (SBP)

There was no significant difference in mean SBP ($p > .05$) between exercise performed in the supine and upright position (Appendix J). The mean SBP value of both supine exercise trials ($\overline{X}$ = 152 mm/Hg) was not significantly different from the mean SBP value of both upright exercise

Figure 3: Mean HR Values by Workload and Position



trials ($\overline{X}$ = 148 mm/Hg). The means and the standard deviations of both test trials in the supine and upright position at workloads of 200, 400, 600, and 800 are presented in Figure 4.

A further evaluation of the test variables (Appendix J) revealed no significant difference between SBP's in test 1 and test 2, or among the interaction of position and test 1 or 2, position and workload, test 1 or 2 and workload or among position, test 1 or 2 and workload. A significant difference in SBP was demonstrated between all workloads.

These data indicated that there was no significant difference in the mean SBP responses between exercise performed in the supine and upright position. Consequently, null hypothesis 4 was accepted.

Rating of Perceived Exertion (RPE)

The RPE was significantly greater ($p < .007$) in the supine position when compared to the upright position (Appendix J). The mean RPE's of both supine exercise trials ($\overline{X}$ = 10.9) was .9 less than the mean RPE's of both upright exercise trials ($\overline{X}$ = 10.0). The means and the standard deviations of both test trials in the supine and upright positions at workloads of 200, 400, 600, and 800 are presented in Figure 5.

A further evaluation of the test variables (Appendix J) revealed a significant difference between workloads, test 1 and test 2, and interaction of position and workload. The Tukey post-hoc test was performed on the results of the data related to position and workload. The Tukey post-hoc test revealed that a significant difference was found between the upright and supine positions at workloads of 600 KPM and 800 KPM. There were no significant differences at 200 or 400 KPM. The difference

Figure 4: Mean SBP (mm/Hg) Values by Workload and Position

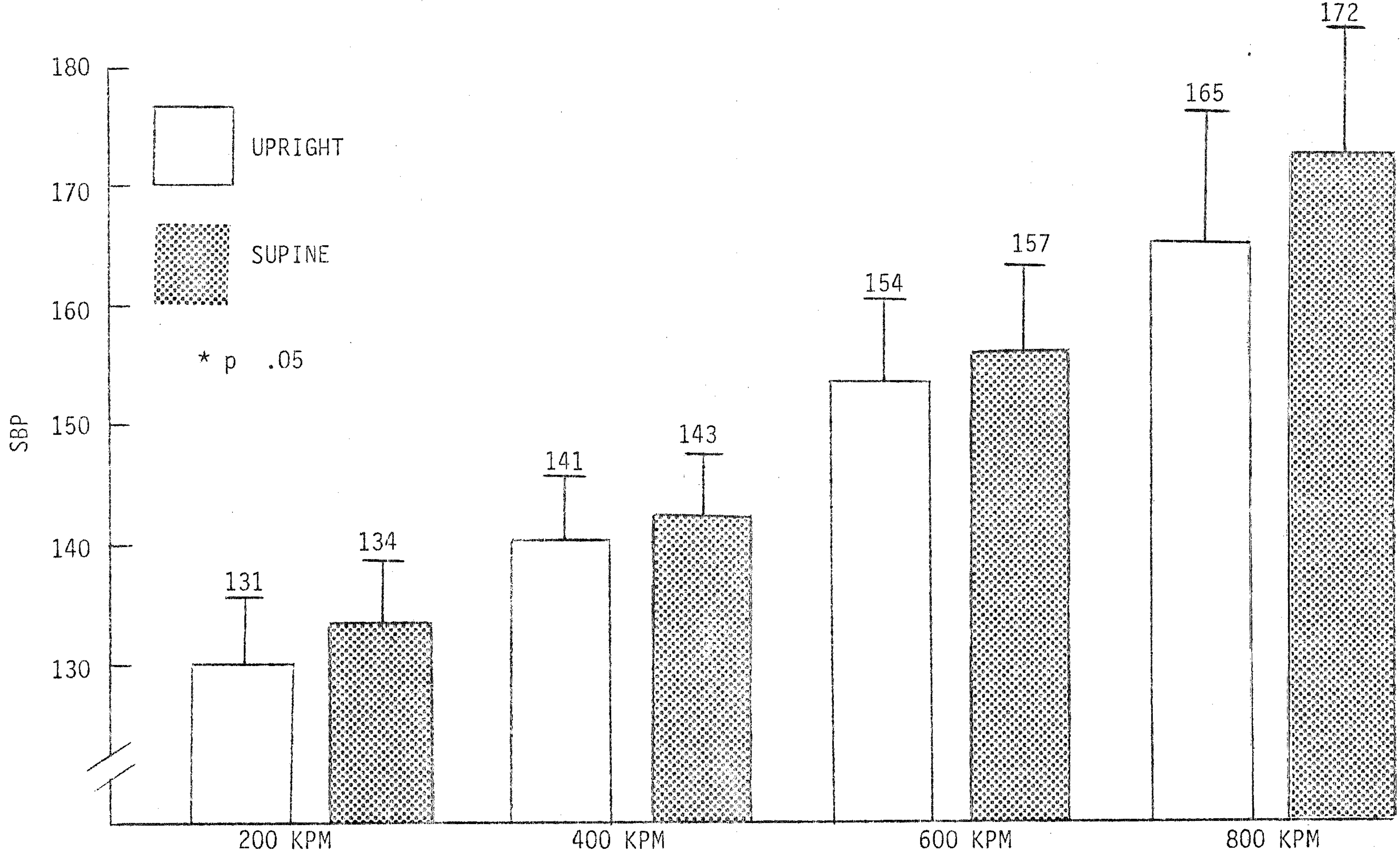
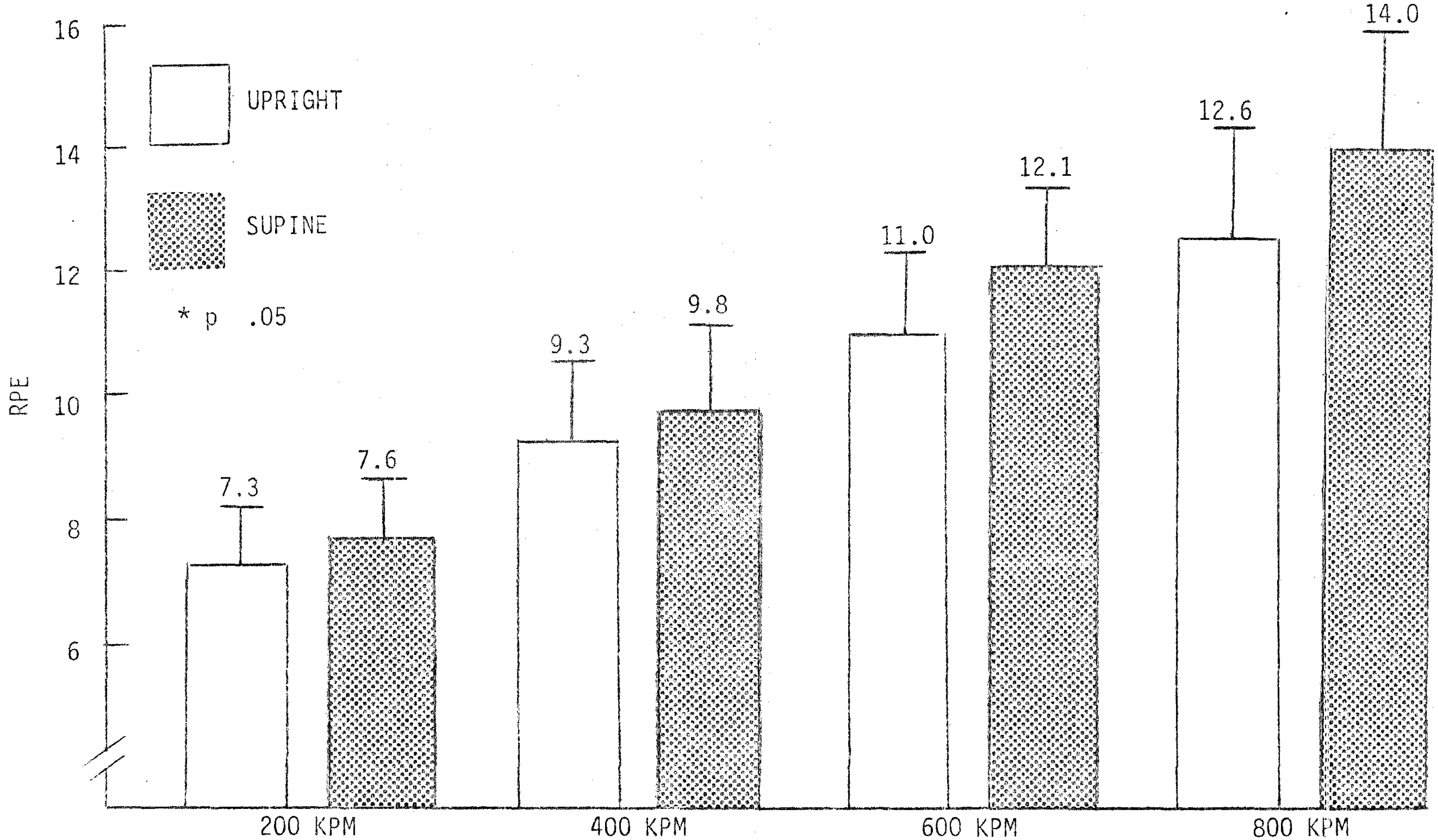


Figure 5: Mean RPE Values by Workload and Position



in RPE found between each of the various workloads was found to be significant. There were no significant differences in RPE among position and test 1 or 2, test 1 or 2 and workload or among position, test 1 or 2 and workload. However, there was a significantly greater RPE value in T_2 when compared to T_1.

These data indicated that the RPE in the supine exercise position was significantly greater than in the upright position. Consequently, null hypothesis 5 was rejected.

Hip Angle Measurements

There was no significant difference in the hip angle measurements between the supine and upright positions ($p > .05$). The mean hip angle in the extended leg position was 161° in the supine position and 157° in the upright position. The mean hip angle in the flexed leg position was 112° in the supine and 109° in the upright.

CHAPTER V

DISCUSSION

The purpose of this study was to compare selected metabolic and hemodynamic values and the ratings of perceived exertion during supine and upright bicycle ergometry. It was also the purpose of this study to develop and compare linear regression equations in the two positions. The literature presents conflicting results in VO_2, HR, and SBP measurements performed in both the supine and upright positions. No studies that evaluated RPE and the linear regression equation of workload and VO_2 during exercise in the two positions were found by this investigator.

Oxygen Consumption (ml/min)

The results of the present study indicated that subjects performed at a significantly lower VO_2 in the supine position than in the upright position at workloads of 200, 400, 600, and 800 KPM. The results of Stenberg et al. (1967) are in agreement with the results of the current study in that the VO_2 was less during exercise in the supine position. Bevegard et al. (1963) reported a significantly lower VO_2 between the two positions at 800 KPM, but showed no significant difference in VO_2 at 1600 KPM. The present results also conflicted with studies by Bevegard et al. (1960) and Granath et al. (1963) who reported no significant difference between the two positions. Methodological variations among studies such as different upright and supine bikes, different pedaling positions and different exercise protocol might explain the conflicting results.

The decrease in VO_2 could be explained by the interaction and change in S.V., a-vO_2, and $\dot{Q}$ that have been shown to occur during the supine position. Bevegard et al. (1963), Granath et al. (1964), and Stenberg et al. (1967) reported significantly greater SV's and $\dot{Q}$'s in the supine position with a significantly lower a-vO_2. The change in SV during the supine position has been explained by a shift in blood from the legs to the thorax, thus resulting in an increased stroke volume by an increased venous return (Sjostrand, 1953; and Weissler et al. 1959) and an increased diastolic filling.

Although statistically significant differences were reported in this study, actual mean differences would be of little importance in a clinical setting. The mean difference of both exercise trials was 5.4 percent or 76 ml/min between the two positions. This difference amounts to less than 1 ml/kg/min or approximately one-third of a MET. This difference is within the error of the direct O_2 consumption or prediction equation techniques. These results are within a range of the magnitude to Bevegard et al (1963) at 800 KPM who showed a difference of 95 ml/min or 5.2 percent from the supine to the upright position and Stenberg et al. (1967) who showed a 106 ml/min difference (5.6 percent) between exercise performed in the two positions.

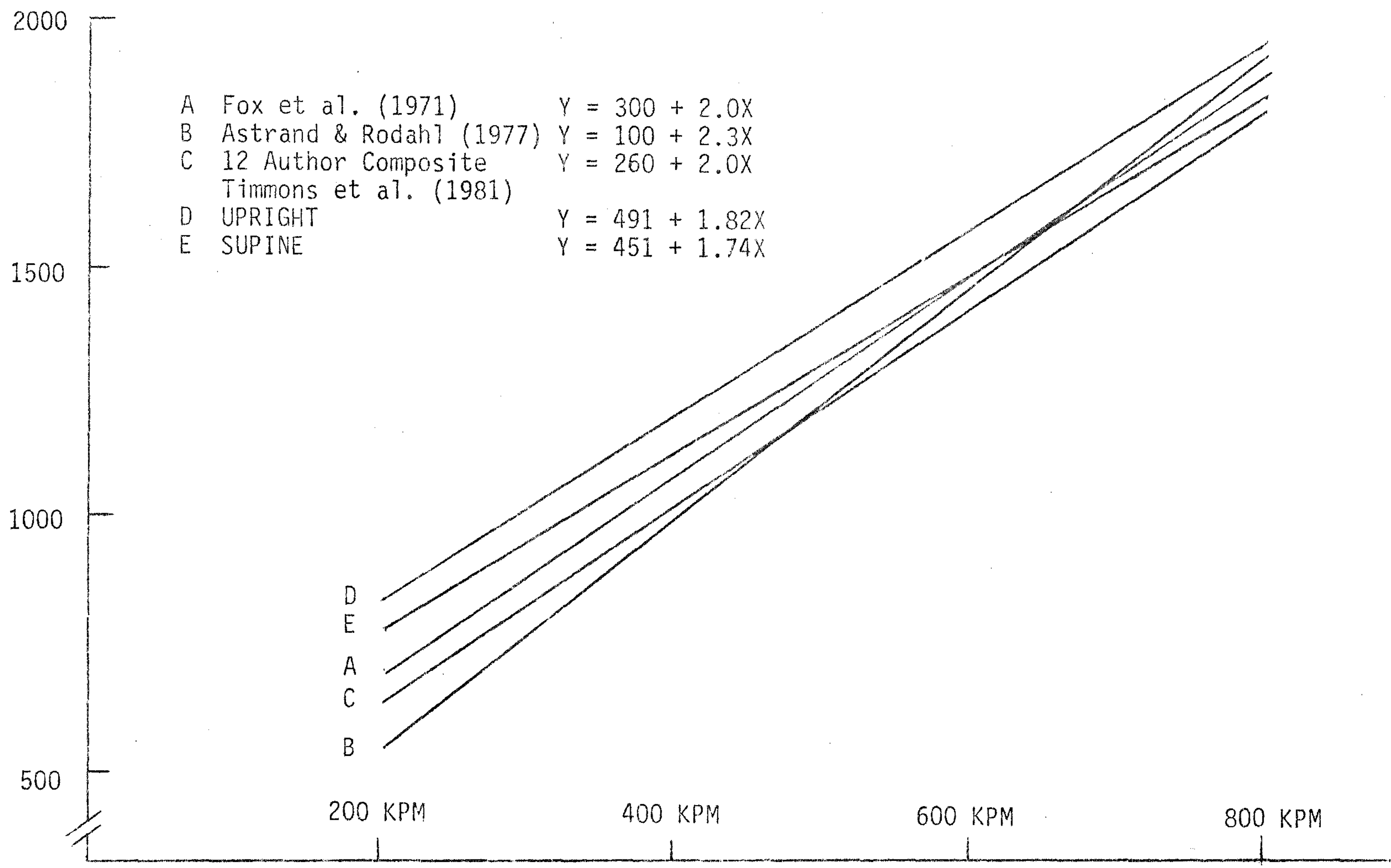
Oxygen Consumption (Linear Regression Equation)

Two linear regression equations were calculated from the present data. In the upright position the equation $Y = 491 + 1.82X$ was calculated, and in the supine position the equation $Y = 451 + 1.74X$ was determined. Statistical analysis indicated that the slopes of these equations were not significantly different ($p > .05$). But, statistical evaluation of the y-intercepts revealed a significantly greater value in the upright position ($p < .01$). The results that revealed the y-intercept to be greater in the upright position agrees with the VO_2 data.

The slope of the linear regression equations represents the approximate oxygen requirement of performing 1 KPM of work. Balke (1960) suggested the constant of 1.80 ml/min to be equivalent to 1 KGM during any activity. The results of this study, 1.82 ml/min in the upright position and 1.74 ml/min in the supine position, fall .04 ml/min above and below the values Balke (1960) suggested. Astrand (1958), and Shephard (1973), presented 2.0 ml/min as the energy equivalent of 1 KPM of bicycle ergometry exercise. Wahlund (1948) presented the smallest energy equivalent value of 1 KPM of bicycle exercise. Wahlund's value was 1.7 ml/min. Figure 6 graphically displays the present linear regression equations and several other current linear regression equations. From this figure it appears that the linear regression equations presented by the present study fell within the range of the other linear regression equations.

The y-intercept of the present study in the upright position (491 ml/min) and supine position (451 ml/min) were 191 ml/min and 151 ml/min higher than the values presented by Fox et al. (1971) and by Astrand and Rodahl (1977). The y-intercept would theoretically represent the VO_2 at 0 workload. The increase in the y-intercept seen in the present study could be due to the fact that resting VO_2 was not calculated into the linear regression equation. When the resting VO_2 is included in the linear regression equation, the y-intercept decreases. Studies presenting

Figure 6: Linear Regression Equations and Lines of Several Authors



prediction equations did not specify whether resting values were included in the calculations.

Although the y-intercept values of the upright and supine bicycle exercise were statistically different, their clinical importance would be minimal. A 5.5 percent difference between the mean of values at 200, 400, 600, and 800 KPM was seen between the two positions.

Heart Rate (HR)

The findings of a significantly lower heart rate in the supine position agreed with the results of Thadani and Parker (1978) and Stenberg et al. (1967). Thadani showed a 12 percent decrease in heart rate between the two positions, which was a decrease of 18 beats per minute. Stenberg et al. demonstrated a decrease of 5 BPM or a 2 percent decrease in the supine position. The present study revealed a decrease of 5 BPM or 4.5 percent in the supine position. Conflicting results concerning HR were presented by Bevegard et al. (1960), Bevegard, et al. (1963), Granath (1964), and Holmgren and Ovenfors (1960), who all demonstrated no significant difference in the HR response between supine and upright exercise ergometry. Lecerof (1971), who used cardiac subjects, reported a 5 BPM increase in HR ($p < .05$) in the supine position which conflicted with all other HR results.

The decrease in HR may be explained by the increase in SV and $\dot{Q}$ that results during a supine position. The increase in SV and $\dot{Q}$ may cause an increase in aortic and carotid pressure, thus causing a decrease in sympathetic stimulation and reducing HR. A statistical difference in HR was shown in the present study, but again the clinical importance of such a small change in HR would be limited.

Systolic Blood Pressure (SBP)

The results of SBP in the present study are in general agreement with the literature. The present investigation reported no significant difference in SBP between the supine and upright positions. Bevegard et al. (1960), Thadani and Parker (1978), and Lecerof (1971) presented results of no significant difference in SBP when comparisons were made between the supine and upright positions. Bevegard et al. (1963) reported no significant differences at 800 KPM, but also reported a significant increase in blood pressure of 4.7 percent at the 1600 KPM workload.

An increase in SBP was expected due to the increase in SV and $\dot{Q}$. These differences may have been too minor to effect a SBP change.

Rating of Perceived Exertion (RPE)

The mean RPE values during supine and upright bicycle ergometry in the present study call for some close attention, since no measurement of RPE during the two bicycle exercise positions could be found in the literature. The results of the current study revealed a significant difference in RPE at workloads of 600 and 800 KPM, but no significant differences at 200 and 400 KPM.

It can be speculated that these results occurred because at the higher workloads the body weight provides additional force to create the work in the upright position. In the supine position this additional force is not available, and local muscle fatigue results. Maximal VO_2 and HR values have been shown during supine and upright exercise to be greater in the upright position (Lecerof, 1971; Bevegard, 1963).

Therefore, the same absolute workload would be a greater relative workload in the supine position. Thus the higher rating of perceived exertion could be explained. It is possible the RPE in the supine position may more closely represent local leg fatigue rather than total body fatigue. It is also possible that some other unmeasured metabolic or neural factor contributed to the decrease in RPE.

Test trial 1 and test trial 2 were also shown to be significantly different during the present investigation. These test-retest results have not been reported in the literature. These results were independent of position, and both positions demonstrated the RPE to be significantly less on the second trial. One explanation for this RPE difference may be that the first test acted as a learning experience, therefore the second test was perceived to be easier. These findings do not agree with the data collected on VO_2, HR, SBP or linear regression equations, where no significant difference was seen between T_1 and T_2.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The present investigation was conducted to examine the effects of supine and upright positions during bicycle exercise on metabolic, hemodynamic and perceived exertion values. The evaluation included a statistical comparison of VO_2, HR, SBP, RPE and the linear regression equations in both positions.

Data were collected on 16 male subjects who were randomly assigned to one of two testing orders. Half of the subjects performed first in the supine position, while the other half performed first in the upright position.

A three-factor analysis of variance with repeated measures on all variables was performed on all data. When a significant difference was found between the interaction of any test variable, the Tukey post-hoc test was performed to locate the significant difference between paired means. A paired t-test was performed on data collected on hip angle measurements. The .05 level of significance was used to reject the null hypostheses.

Results indicated that several variables were significantly different when comparisons were made between the upright and supine positions. Oxygen consumption (VO_2) in the supine position was significantly less when compared to the upright values. However, the slope of the line calculated by regression analysis of workload and VO_2 indicated no significant difference between the supine and upright positions. Heart Rate was also significantly less in the supine position when compared to the upright position. Ratings of perceived exertion (RPE) were significantly greater at workloads of 600 and 800 KPM in the supine position, but no significant difference was demonstrated at workloads of 200 and 400 KPM. The RPE was also significantly less from test trial 1 to test trial 2.

There were no significant differences seen in SBP between the two positions. There were also no significant differences found in hip angle measurements between the two positions.

Although statistical significance resulted from the analysis on VO_2, HR, the y-intercept of the linear regression equations and RPE, in clinical evaluations the small differences would be of little importance. The mean VO_2 was one-third of MET less in the supine position and the HR was 5 BPM less in the supine position. The y-intercept demonstrated a decrease in the supine position in agreement with the VO_2 data (one-third MET). The RPE difference of an absolute value of 1 at identical workloads would not be very discriminating.

Conclusions

The purpose of this study was to determine the effect of the supine and upright positions on the metabolic cost (VO_2), linear regression equations, hemodynamics, and perceived exertion of bicycle ergometry. Oxygen consumption (VO_2), HR, SBP and RPE were measured during two test trials in each position at workloads of 200, 400, 600, and 800 KPM. As a result of the statistical analysis performed, the following conclusions would seem appropriate within the limitations of the study:

1. There was a significant difference between the mean oxygen consumptions at workloads of 200, 400, 600, and 800 KPM when measured in the supine and upright positions.

2. There was a significant difference between the linear regression lines calculated during exercise performed at 200, 400, 600, and 800 KPM in the supine and upright positions. The slope of the linear regression equations were not significantly different, but the y-intercepts were significantly less in the supine position.

3. There was a significant difference between the mean heart rates at workloads of 200, 400, 600, and 800 KPM when measured in the supine and upright positions.

4. There was no significant difference between the mean systolic blood pressures at workloads of 200, 400, 600, and 800 KPM when measured in the supine and upright positions.

5. There was no significant difference between the mean ratings of perceived exertions at workloads of 200 and 400 KPM when measured in the supine and upright positions. But, there were significant differences at workloads of 600 and 800 KPM.

Recommendations

Based on the conclusions of this study, the following recommendations were made in regard to possible further research:

1. A study should be conducted using progressive workloads to maximal values while comparing supine and upright positions.

2. Male and female comparisons should be evaluated during supine and upright bicycle exercise.

3. Various population groups should be evaluated during the performance of bicycle exercise in the supine and upright positions.

4. Further evaluation of RPE should be conducted during exercise performed in the supine position.

5. A linear regression equation should be calculated for a cardiac population in the supine position.

REFERENCES CITED

Allen, E. Myocardial Imaging. V.A. Medical Center, Oklahoma City, Oklahoma, 1977.

American College of Sports Medicine. Guidelines for graded exercise testing and exercise prescription. Philadelphia: Lea & Fabiger, 1980.

American College of Sports Medicine. Calculation of the relative energy expenditure for various activities in mets. In supplement to guidelines for graded exercise testing and prescription. Philadelphia: Lea & Fabiger, 1975.

American Heart Association. The exercise standards book. 1978.

American Heart Association. Exercise testing and training of apparently healthy individuals: a handbook for physicians. The Committee on Exercise, 1972.

Asmussen, E., Christensen, E. & Nielsen, M. Scandinavian Archives of Physiology, 1939, 81 (4), 212.

Asmussen, E. & Nielsen, M. Acta Physiological Scandinavica, 1947, 14, 171.

Astrand, I. In S. Fox (ed.), Coronary heart disease. Denver: International Medical Corporation, 1974.

Astrand, I. The physical work capacity of workers 50-64 yr olds. Acta Physiological Scandinavica, 1958, 42, 73.

Astrand, I. Aerobic work capacity in men and women with special reference to age. Acta Physiological Scandinavica, 1960, 49, Supplement 169.

Astrand, P. Work tests with the bicycle ergometer. Monark-Crescent AB, Varberg, Sweden.

Astrand, P. Experimental studies of physical working capacity in relation to sex and age. Copenhagen, Munksgard, 1952.

Astrand, P. & Rodahl, K. Textbook of work physiology. New York: McGraw-Hill Book Company, 1977.

Balke, B. In O. Glasser (Ed.), Medical physics, 3, 50-51. Chicago: The Yearbook Publishers, 1960.

Berger, H., Reduto, L., Johnston, D., Borkowski, H., Sands, M., Cohen, L., Langou, R., Gottschalk, A. & Zaret, B. Global and regional left ventricular response to bicycle exercise in coronary artery disease. Assessment by quantitative radionuclide angiocardiography. American Journal of Medicine, 1979, 66, 13.

Bevegard, S. Studies on the regulation of the circulation in man with special reference to stroke volume and the effects of muscular work, body position, and artificial induced variations of heart rate. Acta Physiological Scandinavica, 1963, 57, Suppl. 200, 1-36.

Bevegard, S., Holmgren, A. & Jonsson, B. Circulatory studies in well-trained athletes at rest and during heavy exercise, with special reference to stroke volume and the influence of body position. Acta Physiological Scandinavica, 1963, 57, 26-50.

Bevegard, B., Holmgren, A. & Jonsson, B. The effects of body position on the circulation at rest and during exercise with special reference to the influence on the stroke volume. Acta Physiological Scandinavica, 1960, 49, 279-298.

Bobbert, A. Physiological comparison of three types of ergometry. Journal of Applied Physiology, 1960, 15, 1007-1015.

Borer, J., Bacharach, S., Green, M., Kent, K., Johnston, G. & Epstein, S. Effects of nitroglycerine on exercise induced abnormalities of left ventricular regional function and ejection fraction in coronary artery disease. Assessment by radionuclide cineangiography in symptomatic and asymptomatic patients. Circulation, 1978, 57, 314.

Borg, G. Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitation Medicine, 1970, 2, 92-98.

Borokowski, H., Berger, H., Langou, R., Cohen, L., Gottschalk, A. & Zaret, B. Rapid assessment of left ventricular performance during exercise induced myocardial ischemia, First-pass radionuclide technique. Circulation, 1977, 56, Suppl. 3, 198.

Bygdeman, S. & Wahren, J. Influence of body position on the anginal threshold during leg exercise. European Journal of Clinical Investigations, 1974, 4, 201-206.

Christensen, E. Arbeitsphysiologie, 1931, 4, 154.

Christensen, E. & Hansen, O. Scandinavian Archives of Physiology, 1939, 81, 137.

Chung, E. Exercise electrocardiography. Baltimore: The Williams and Wilkins Co., 1979.

Clarke, H. & Clarke, D. Advanced Statistics. New Jersey: Prentice Hall, 1972.

Consloazio, C., Johnson, R. & Pecora, L. Physiological measurements of metabolic function in man. New York: McGraw-Hill Book Co., 1963.

Dill, D. Oxygen used in horizontal and graded walking and running on the treadmill. Journal of Applied Physiology, 1965, 20, 19-22.

Ellstad, A. Stress testing principles and practices. Philadelphia: E.A. Davis Co., 1975.

Fox, S., Naughton, J. & Haskell, W. Physical activity and the prevention of coronary heart disease. Annels of Clinical Research, 1971, 3, 404.

Granath, A., Jonsson, B. & Strandell, T. Circulation in healthy old men studied by right heart catheterization at rest and during exercise in the supine sitting position. Acta Medica Scandinavica, 1964, 176, 425-446.

Holmgren, A. & Ovenfors, C. Heart volumes at rest and during muscular work in the supine and in the sitting position. Acta Medica Scandinavica, 1960, 167, 267-277.

Kattus, A. In Ellestad, M. Stress testing principles and practice. Philadelphia: F.A. Davis Co., 1975.

Larson, L. Fitness, health, work capacity international standards for assessment. International committee for the standardization of physical fitness tests. New York: Macmillan Publishing Co., 1974.

Lecerof, H. Influence of body position on exercise tolerance, heart rate, blood pressure, and respiration rate in coronary insufficiency. British Heart Journal, 1971, 33, 78-83.

Margaria, R. Energy cost of running. Journal of Applied Physiology, 1963, 18, 367-370.

Muller, E. Arbeitsphysiologie, 1953, 15, 196.

Nagle, F., Balke, B. & Naughton, J. Gradational step tests for assessing work capacity. Journal of Applied Physiology, 1965, 20, 745-748.

Naughton, J. & Haider. In J. Naughton & Hellerstein, Exercise testing in coronary heart disease. New York: Academic Press, 1973.

Nielsen, M. Scandinavian Archives of Physiology, 1936, 74, 1936.

Pugh, R. The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer. Journal of Physiology, 1974, 241, 795-808.

Quinton Instrument Company. Print QL-0768279. 2121 Terry Avenue, Seattle, Wa., 1979.

Reduto, J. & Zaret, C. In P. Cohn (ed.), Diagnosis and therapy of coronary artery disease. Boston: Little Brown & Co., 1979.

Rhyming, I. A modified harvard step test for the evaluation of physical fitness. Arbeitsphysiologie, 1954, 15, 235.

Shennum, P. & deVries, H. The effect of saddle height on oxygen consumption during bicycle ergometer work. Medicine and Science in Sports, 1976, 8 (2), 119-121.

Shephard. Coronary heart disease. Denver: International Medical Corporation, 1973.

Sinning, W. Experiments and demonstrations in exercise physiology. Philadelphia: W.B. Saunders, 1975.

Sjostrand, T. Volume and distribution of blood and their significance in regulating circulation. Physiological Review, 1953, 33, 202.

Stenberg, J., Astrand, P., Ekblom, J., Royce, J. & Saltin, B. Hemodynamic response to work with difference muscle groups, sitting & supine. Journal of Applied Physiology, 1967, 22, 61.

Strandell, T. Heart rate and workload at maximal working intensity in old men. Acta Medical Scandinavica, 1964, 176, 301.

Thadani, U. & Parker, J. Hemodynamics at rest and during supine sitting bicycle exercise in normal subjects. The American Journal of Cardiology, 1978, 41, 52-59.

Weissler, A., Leonard, J. & Warren, J. Effects of posture and atropine on the cardiac output. Journal of Clinical Investigation, 1957, 36, 1656.

APPENDIX A

PRE-EXERCISE MEDICAL HISTORY FORM

PRE-EXERCISE MEDICAL HISTORY FORM

NAME ______________ DATE __________ PHONE # ____________

AGE ______________ ADDRESS ____________________

DO YOU HAVE, OR HAVE YOU EVER HAD:

Diabetes	____ YES	____ NO	____________
Rheumatic Fever	____ YES	____ NO	____________
Heart Murmur	____ YES	____ NO	____________
High Blood Pressure	____ YES	____ NO	____________
Abnormal Heart Rhythm	____ YES	____ NO	____________
Disease of the Arteries	____ YES	____ NO	____________
Lung Disease	____ YES	____ NO	____________
Epilepsy	____ YES	____ NO	____________
Chest Pain or Pressure	____ YES	____ NO	____________
Dizziness or Fainting	____ YES	____ NO	____________
Difficulty in Breathing	____ YES	____ NO	____________
Heart Palpatations	____ YES	____ NO	____________
Joint or Muscular Problems	____ YES	____ NO	____________

Are you currently on any medication? ____ YES ____ NO ____________

Do you have discomfort, shortness of breath, or pain with exercise?

____ YES ____ NO

Do you presently have any health problems? ____ YES ____ NO

Did your last physical examination reveal any problems? ____ YES ____ NO

When did you last have a physical examination? __________ (date)

Do you expect any physical problems with your participation in physical exercise? ____ YES ____ NO

______________________________ ______________

SIGNATURE DATE

APPENDIX B

INFORMED CONSENT FORM

INFORMED CONSENT FORM

SUPINE AND UPRIGHT BICYCLE ERGOMETRY

I ______________________ consent to participate in 4 bicycle exercise evaluations administered by Dan Timmons. All evaluations will be performed at the Human Performance Laboratory on the campus of the University of Wisconsin-La Crosse. I understand that the procedures of this test have been approved by Glen Porter, Ph.D. and Donald Kirkendall, Ph.D., the supervising thesis committee.

I understand that during the evaluations I will ride a bicycle ergometer twice in the supine position and twice in the upright position. Four submaximal progressive workloads will be chosen during the exercise period lasting 3 minutes per workload. Heart rate and blood pressure will be monitored before and during the test period. A headset and mouthpiece will be used to collect and measure oxygen consumption.

Every effort will be made to conduct the evaluation in such a way to minimize discomfort and risk. However, I understand that there are potential risks involved with exercise tests. These include lightheadedness, fainting, leg and chest discomfort, and very rarely heart attack and sudden death. I also understand that both the laboratory and technicians are equipped and prepared for such emergency situations.

I understand that the administrator of this exercise evaluation will answer all questions concerning procedures, risks, or benefits involved with participation in this study. I realize that I may withdraw from participation at any time I so desire.

I understand the general procedures and am aware and accept the risks involved as outlined above.

______________________ ______________
subject date

____
witness

APPENDIX C

INSTRUCTIONS FOR PERCEIVED EXERTION

INSTRUCTIONS FOR PERCEIVED EXERTION

You are going to take part in a bicycle ergometer exercise test. We will be measuring various physiological variables, and we want you to estimate how hard you are working. This estimate of how hard you are working is called perceived exertion. We will show you a scale of numbers from 6 to 20 which has a verbal description of the work intensity with each of the odd numbers. With this scale, 6 corresponds to how you feel at rest, and 20 corresponds to total exhaustion. Every three minutes we will ask you to point to the number which best matches your feeling of perceived exertion. By perceived exertion we mean the total feelings of physical stress, effort, and fatigue. Don't concentrate on any single factor such as leg fatigue or shortness of breath, but instead try to concentrate on the total inner feeling of exertion. Don't try to underestimate or overestimate your feeling of exertion. Try to estimate as accurately as possible.

<u>BORG SCALE</u>

6
7 - VERY VERY LIGHT
8
9 - VERY LIGHT
10
11 - LIGHT
12
13 - SOMEWHAT HARD
14
15 - HARD
16
17 - VERY HARD
18
19 - VERY VERY HARD
20

APPENDIX D

SUPINE AND UPRIGHT BICYCLE PROTOCOL

SUPINE AND UPRIGHT BICYCLE PROTOCOL

Stage	Min	KPM[A]	Watts	KP[B]	RPM[C]
1	0-3	resting	-	-	-
2	3-6	200	33.3	.667	50
3	6-9	400	66.6	1.333	50
4	9-12	600	100	2.0	50
5	12-15	800	133.3	2.67	50
6	15-17	300	50	1.0	50

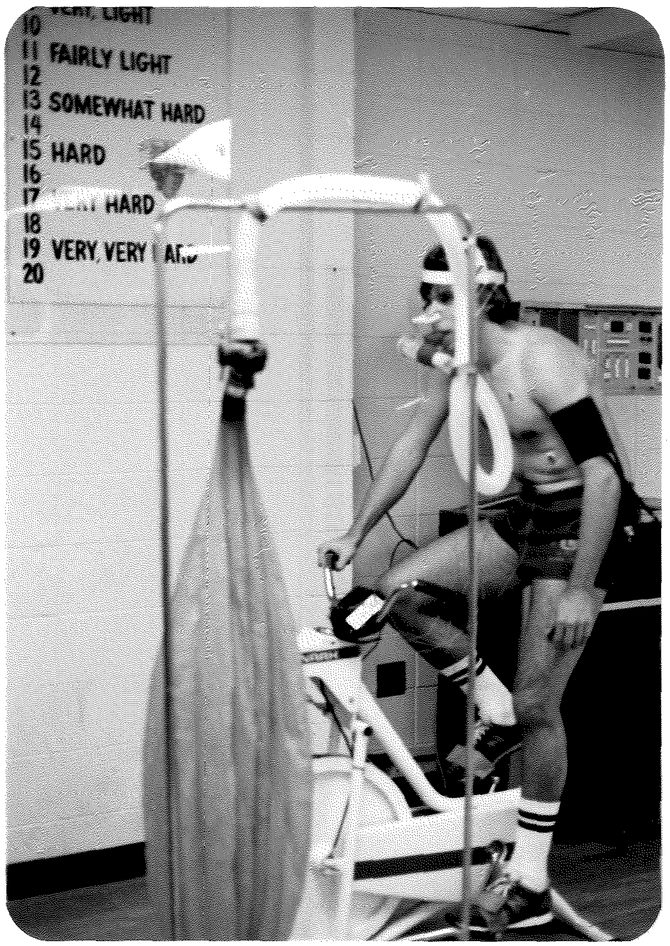
A = killopond meters

B = killopond

C = revolutions per minute

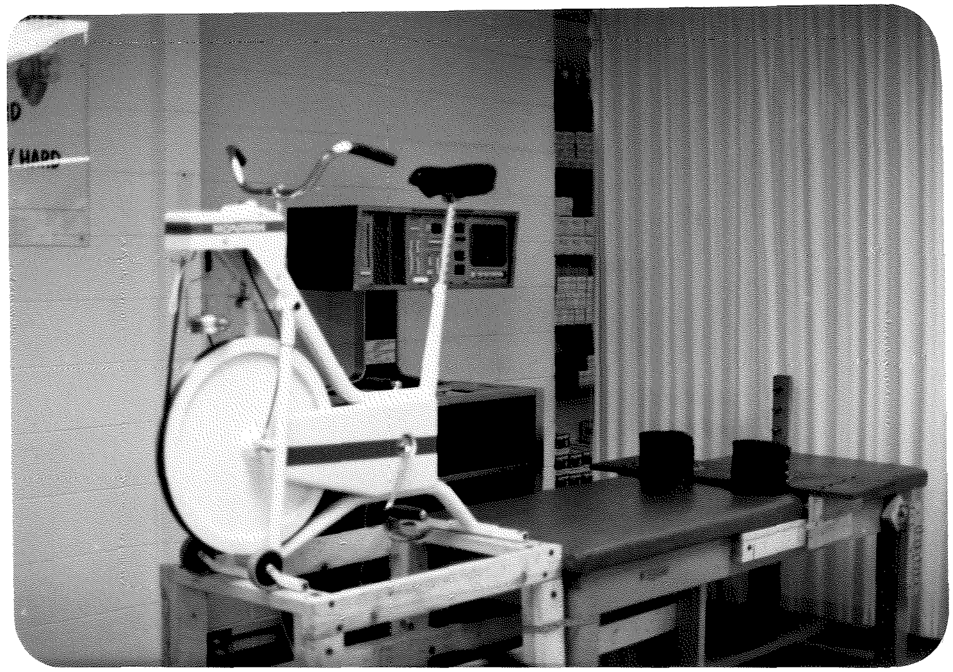
APPENDIX E

THE UPRIGHT BICYCLE ERGOMETER


10
11 FAIRLY LIGHT
12
13 SOMEWHAT HARD
14
15 HARD
16
17
18
19 VERY, VERY
20

APPENDIX F

THE SUPINE BICYCLE ERGOMETER




FAIRLY LIGHT
SOMEWHAT HARD
HARD
VERY HARD

APPENDIX G

CORRECTION FACTOR FOR THE DRY GAS METER

Tissot Tank Values Liters	A.M.C. Dry Gas Meter Liters
20.9	20.4
26.5	26.7
27.4	28.1
23.8	23.9
34.9	35.4
34.6	34.1
38.0	38.4
39.6	40.3
53.0	53.6
57.4	57.9
56.9	57.4
65.1	65.6
90.3	91.0
91.1	92.5
101.9	102.5
105.5	106.1
57.1	57.6
104.6	103.9
99.9	100.0
104.1	104.0
$\overline{X}$ = 61.63	$\overline{X}$ = 61.97

r = .9999

Correction Factor = .9945

APPENDIX H

THE DETERMINATION OF VO_2

DEFINITION OF SYMBOLS FOR GAS TRANSFORMATIONS

$FeCO_2$ - Fraction of expired carbon dioxide

FeN_2 - Fraction of expired nitrogen

FeO_2 - Fraction of expired oxygen

P bar - Barometric pressure

P H_2O - Partial pressures of water

STPD - Standard temperature pressure dry correction factor

T gas - Gas temperature ^oC

Ve(ATPS) - Volume of expired gas at atmospheric temperature and pressure saturated

$VeCO_2$ - Volume of expired carbon dioxide

VeO_2 - Volume of expired oxygen

Ve(STPD) - Volume of expired gas at standard temperature pressure dry

ViO_2 - Volume of inspired oxygen

Vi(STPD) - Volume of inspired gas at standard temperature pressure dry

VO_2(STPD) - Volume of oxygen consumed

W - Weight of subject in kilograms

GAS TRANSFORMATIONS

$$STPD = \frac{273^{o}}{273^{o} + T\ gas} \times \frac{P\ bar - P\ H_2O}{760}$$

$$Ve(STPD) = Ve(ATPS) \times STPD$$

$$VeO_2 = Ve(STPD) \times \frac{FeO_2}{100}$$

$$Vi(STPD) = Ve(STPD) \times \frac{FeN_2}{.7904}$$

$$FeN_2 = 100 - (FeO_2 + FeCO_2)$$

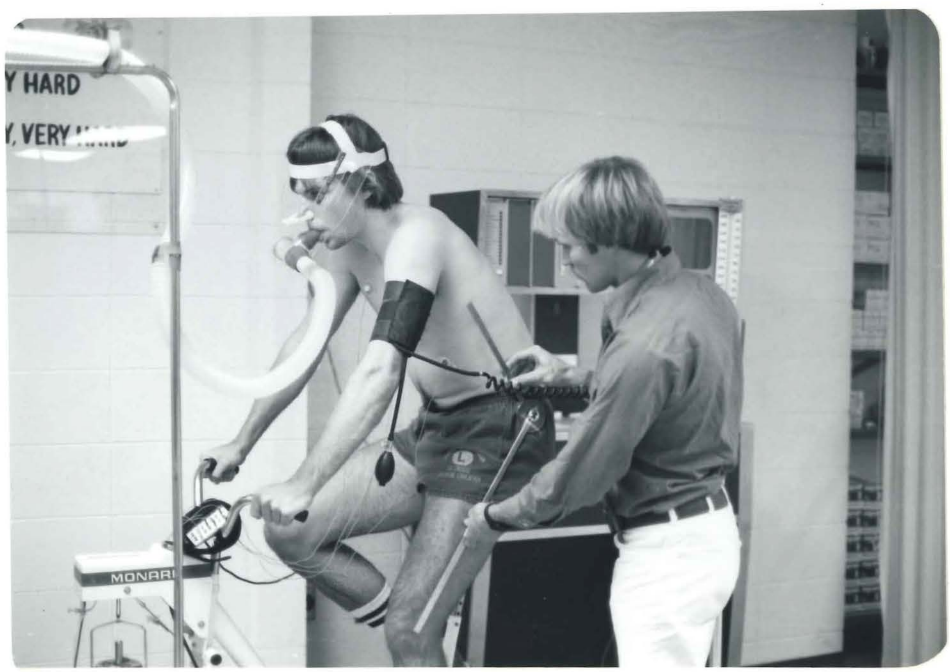
$$ViO_2 = Vi(STPD) \times .2093$$

$$VO_2(STPD) = ViO_2 - VeO_2$$

$$VO_2(STPD)\ ml/kg = \frac{VO_2(STPD)\ 1\ min}{W}$$

APPENDIX I

HIP ANGLE MEASUREMENTS


Y HARD
Y, VERY
MONAR

APPENDIX J

ANALYSIS OF VARIANCE TABLES

Table 1: Analysis of Variance for VO_2 (ml)

Source	SS	df	MS	F	p
Position (P)	367160.31250	1	367160.31250	31.63	.001
ERROR	174131.21875	15	11608.74805		
Test Trial (T)	14565.43750	1	14565.43750	1.19	.292
ERROR	183442.15625	15	12229.47656		
P X T	12754.87500	1	12754.87500	.79	.389
ERROR	243511.75000	15	16234.11719		
Workload (W)	40700032.00000	3	13566678.00000	1494.54	.001
ERROR	408486.87500	45	9077.48633		
P X W	30350.12500	3	10116.70898	2.32	.089
ERROR	196630.40625	45	4369.56445		
T X W	38536.59375	3	12845.53125	2.62	.063
ERROR	221017.59375	45	4911.50195		
P X T X W	7070.81250	3	2356.93750	.38	.767
ERROR	278431.31250	45	6187.36230		

Table 2: Analysis of Variance for HR

Source	SS	df	MS	F	p
Position (P)	1991.39258	1	1991.39258	6.48	.022
ERROR	4611.73438	15	307.44897		
Test Trial (T)	34.51563	1	34.51563	.43	.522
ERROR	1201.86108	15	80.12407		
P X T	60.06250	1	60.06250	.48	.500
ERROR	1888.31274	15	125.88751		
Workload (W)	48209.06250	3	16069.68750	438.99	.001
ERROR	1647.28076	45	36.60624		
P X W	106.39075	3	35.46358	2.97	.042
ERROR	537.98401	45	11.95520		
T X W	71.95319	3	23.98439	2.27	.094
ERROR	476.17194	45	10.58160		
P X T X W	32.03131	3	10.67710	1.00	.400
ERROR	479.09375	45	10.64653		

Table 3: Analysis of Variance for SBP

Source	SS	df	MS	F	p
Position (P)	1076.66016	1	1076.66016	1.80	.200
ERROR	8982.03125	15	598.80212		
Test Trial (T)	377.81689	1	377.81689	1.80	.199
ERROR	3144.12354	15	209.60825		
P X T	481.25293	1	481.25293	2.32	.149
ERROR	3113.68457	15	207.57898		
Workload (W)	46784.15625	3	15594.71875	142.57	.001
ERROR	4922.39453	45	109.38655		
P X W	134.57422	3	44.85807	1.50	.226
ERROR	1341.48779	45	29.81084		
T X W	239.29297	3	79.76433	2.29	.091
ERROR	1566.51880	45	34.81153		
P X T X W	117.10571	3	39.03524	.94	.428
ERROR	1861.70728	45	41.37127		

Table 4: Analysis of Variance for RPE

Source	SS	df	MS	F	p
Position (P)	44.72264	1	44.72264	9.94	.007
ERROR	67.46486	15	4.49766		
Test Trial (T)	18.59766	1	18.59766	15.01	.001
ERROR	18.58984	15	1.23932		
P X T	.00391	1	.00391	.00	.968
ERROR	34.43361	15	2.29557		
Workload (W)	1220.38696	3	406.79565	186.94	.001
ERROR	97.92580	45	2.17613		
P X W	10.04298	3	3.34766	6.54	.001
ERROR	23.01954	45	.51155		
T X W	.10547	3	.03516	.08	.969
ERROR	18.95704	45	.42127		
P X T X W	1.13672	3	.37891	.91	.442
ERROR	18.67579	45	.41502		