A SUBMAXIMAL COMBINED ARM AND LEG TEST AS A PREDICTOR OF MAXIMAL OXYGEN CONSUMPTION

by

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B.S., University of Kansas, 1982

Submitted to the Department of Health, Physical Education, Recreation and Dance and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science in Education.

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For the Department

9-20-84
Date thesis accepted

ABSTRACT

This study evaluated the predictive accuracy of a submaximal combined arm and leg test and that of the Astrand-Rhyming bicycle test. The study also determined the predictive accuracy of a submaximal test with the maximal value of a test using the same testing mode.

The testing was conducted at the University of Kansas. Thirty female subjects between the ages of 18 and 31 years, (x = 23) performed a maximal treadmill test, a maximal combined arm-leg test, a maximal bicycle test, a submaximal combined arm-leg test, and a submaximal bicycle test.

The mean measured maximal oxygen consumption was 2.89 (.44) in L/min and 46.82 (4.96) in ml/kg•min for the treadmill, 2.61 (.41) in L/min and 41.64 (4.98) in ml/kg•min for the combined arm-leg, and 2.30 (.32) in L/min and 37.15 (5.22) in ml/kg•min for the bicycle.

A multiple regression equation was computed for predicting V02max from the submaximal heart rate and workload of the tests using the combined arm and leg and the bicycle. The mean value of predicted V02max from the submaximal combined test was 2.88 (.31) in L/min and 47.15 (6.49) in ml/kg•min. The prediction had a correlation value of .73 for L/min and .67 for ml/kg min with the treadmill and standard error of estimate in L/min and ml/kg•min, .21 and 4.82, respectively.

The mean value of the predictive value using the Astrand-Rhyming nomogram for the submaximal bicycle test was 2.51 (.81) in L/min and 40.17 (10.29) in ml/kg•min. These values correlated with the treadmill with values of .71 in L/min and .46 in ml/kg•min. The standard error of estimate when compared to the treadmill were .57 L/min and 9.10 ml/kg.min.

It was concluded that when predicting maximal oxygen consumption, the submaximal combined arm-leg mode will give a more accurate reading than the Astrand-Rhyming submaximal test. Higher correlations between predicted values and measured values are obtained when the values are expressed in L/min instead of ml/kg•min. It was also determined that submaximal testing to predict maximal oxygen consumption is not mode specific.

ACKNOWLEDGEMENTS

I would like to thank the committee for their assistance during the course of this study; without their help this investigation would not have been possible. I would especially like to thank Dr. Tom Thomas for his guidance and encouragement. The statistical procedures would not have been possible without the aid and direction of Dr. Steve Houseworth. I extend my gratitude to Dr. Carol Zebas for her willingness to be a part of my thesis committee.

The gathering of the data was made easier with the help of Anne Lally, Leroy Hiseck, and Frankie Wilson. I appreciate their time and efforts during the course of the investigation. Thanks are extended to Dianna Beebe for her work and construction of the testing platform. I would like to extend my appreciation to Sue Henry for her typing of the composition.

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CHAPTER ONE

Introduction

The maximal oxygen consumption (V02max) is the maximal amount of oxygen that can be carried by the blood and delivered to the cells (84). The increasing popularity of maintaining good health has led to an increase in awareness of an individual's own fitness level (9, 65). It has been stated that the maximal oxygen consumption of an individual is an objective measure of cardiovascular fitness (25, 86).

The only true way to measure V02max is taking the subject to exhaustion. This process requires trained personnel (12) and expensive equipment (26). The subject's health is put at a risk since the whole body is maximally taxed (26). The intricate procedure also can be very time consuming for large groups being tested (91).

Submaximal testing has been used as a valuable screening test for the evaluation of functional capacity of the oxygen transport system (9, 26). Modes such as the bicycle ergometer, step test, and treadmill have been used (12).

Astrand & Rhyming (7) developed a nomogram, from data collected during a standardized submaximal test, to predict V02max. The accuracy of prediction of the nomogram has been under considerable debate. The error of prediction of the nomogram according to DeVries is ±9.3% (27). Submaximal combined arm and leg exercise which utilizes greater muscle mass than legs alone has not been described in the literature as a predictor of V02max.

Purpose of the Study

The purpose of the study was to examine the relationship between a combined arm and leg submaximal test to maximal oxygen consumption. It was also intended to compare the predictive accuracy of two submaximal tests with the corresponding maximal test mode.

Scope of the Study

Thirty female volunteer subjects ranging in ages 18 to 31 years performed one maximal stress test on the treadmill, a submaximal and maximal test on the bicycle ergometer, and a submaximal and maximal test on a combined arm and leg ergometer. The maximal oxygen uptake was predicted from the workload and heart rate during the two submaximal tests. The tests were conducted within three weeks at the University of Kansas in the Spring of 1984 in the Exercise Physiology Laboratory.

Assumptions and Limitations

Six assumptions were made in reference to this study:

1. The subjects were in the same metabolic and physical condition when tested between each testing day.
2. The subjects were not affected by other laboratory conditions.
3. All subjects were not suffering from any cardio-respiratory disease.
4. No training effect took place between testing.
5. The subjects used were a representative sample of the female population between 18 and 31 years of age.
6. All subjects were in a normal emotional and phychological state.

Four limitations of this study were cited:

1. There was no control over the subject's outside activity, but they were "advised" to maintain a normal level of activity.
2. The Astrand-Rhyming test according to Williams (100) is only reliable above .80 when the test is administered once every day for three days. In this study, it was administered only once.
3. Subjects were volunteers, rather than a random sample of all females between the ages 18 and 31 years.
4. Predicted max HR is not always accurate for a given individual in a given age group (27).

Significance of Study

Maximal oxygen consumption is used to determine cardiovascular fitness (25). Various modes have been used to measure VO2max, with the treadmill attaining the highest physiological measures (12, 35, 39, 50, 58, 69). Regardless of the mode used, the measurement of VO2max is potentially dangerous for unfit subjects (26), requires trained personnel (12), requires expensive equipment (26), and is time consuming (91). Submaximal testing has been used to predict maximal oxygen uptake.

Submaximal testing has the following advantages: 1) motivation can be eliminated as a factor in physical fitness screening; 2) older subjects and unconditioned individuals can be tested with less danger; 3) one can estimate the reserve power of the cardiovascular system and evaluate the response of the system to work overload, thus, establishing a functional capacity value (27).

The Astrand-Rhyming bicycle test has been used extensively in submaximal testing with a ±10% error (27). Other submaximal tests include use of the treadmill and step test.

Testing mode variability between maximal and submaximal tests play an important role in the predictive value (17). Previous research indicates that maximal combined arm and leg tests elicit a comparable VO2max to the maximal treadmill test, and a greater VO2max than maximal tests using legs or arms alone (40, 41).

Therefore, a submaximal test using combined arm and leg exercise, utilizing greater muscle mass, should elicit a more accurate prediction of treadmill VO2max than a submaximal bicycle test.

The use of combined arm and leg testing can be used in the laboratory as well as in the clinical setting. If the predictive value of this procedure is more accurate than legs alone or arms alone, its use may become very beneficial to exercise scientists.

Definitions and Abbreviations of Terms

A-V02 Difference - Systemic arteriovenous difference

bpm - beats per minute

EKG - electrocardiogram

HR - heart rate

Kilipond meter - 9.80665 joules (12)

Kilipond meter per minute - 0.16355 watt (12)

L/min - liters per minute

Maximal Oxygen Consumption (V02max) - The maximal functional capacity of the circulorespiratory system

Maximal Test - The subject works until they are no longer able to continue the test. Criteria included RER 1.1 leveling of oxygen consumption, and max HR attained.

ml/kg·min - millileter per kilogram x one minute

Nomogram - A graph containing three scales graduated for different variables so that when a straight line connects the two, the related value may be read directly from the third at the point intersected by the line (104)

Oxygen Uptake (V02) - The difference between the volume of oxygen inspired and that expired, and represents the oxygen used in the electron transport system of the mitochondria

Physical Fitness - The physiological capabilities of the heart, lungs, circulation, and muscles of the body

RER - Respiratory Exchange Ratio - The amount of carbon dioxide produced divided by the oxygen consumed

rpm - revolutions per minute

sd - standard deviation

SEE - Standard Error of Estimate

Submaximal Test - An exercise session in which the subject does not reach maximal heart rate or exhaustion

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Maximal oxygen uptake (VO2max) has been researched in much of the literature (5, 15, 20, 27, 40). Prediction of VO2max from submaximal testing has also undergone extensive study (5-11, 83).

This review will deal primarily with submaximal testing as a predictor of maximal oxygen uptake. The literature review has been divided into the following categories: maximal oxygen consumption and physical fitness; tests which directly measure maximal oxygen consumption; comparison of results elicited by various testing modalities; limitations of maximal oxygen consumption; prediction of maximal oxygen consumption; and submaximal testing as a predictor of maximal oxygen intake.

Maximal Oxygen Uptake and Physical Fitness

The cardiovascular system provides oxygen and nutrients to the muscles and removes metabolic wastes (75). The maximal oxygen consumption (VO2max) is the maximal amount of oxygen that can be delivered to the active muscle by the blood stream (84). Physiological functions associated with normal VO2max include adequate function of the heart, lungs and blood vessels to deliver oxygen from the lungs to the blood. Secondly, oxygen delivery to the tissue by red blood cells must be normal; which includes blood volume, red blood cell count, and hemoglobin concentration. Thirdly, the tissue must have normal capacity to use the oxygen delivered to them (9, 36, 102). The oxygen consumption reflects the overall workload being performed. As an exercising subject reaches the point of exhaustion or fatigue, the V02 will reach a maximal value where an increase in workload will not further increase this value (102). Taylor (88) stated that once V02max is attained, a further increase in workload leads to an oxygen debt. This limited value may reach a level twenty times the amount of oxygen which the body uses at rest.

This limitation of V02max is influenced by: cardiac output, pulmonary ventilation, blood circulation, oxygen diffusion from muscle capillaries to the tissues, and diffusion of oxygen from alveolar air to the blood. Blood volume and hemoglobin also show a high correlation with oxygen intake capacity (9, 67, 74).

There is much controversy over which factor actually limits V02max (9, 67, 72). Williams et al. (100) and Ouellet et al. (70) found that cardiac output ($\dot{Q}$) reached a maximal value at a lower workload than the workload reached with V02max. Therefore, they concluded a circulatory limitation to aerobic capacity.

Other literature (66, 74) pointed to skeletal muscle blood flow as the limitation. Raybrouck (74) reported that $\dot{Q}$ levels off in arm exercise without the heart reaching maximal pumping capacity and thus V02max was limited by skeletal muscle blood flow.

Mitchell (66) stated that V02max was dependent on $\dot{Q}$ and arterial-venous oxygen difference (A-V02). Faulkner et al. (38) stated $\dot{Q}$ decreases with maximal work because stroke volume (SV) decreases as heart rate (HR) reaches 165 beats/minute (bpm). The SV decrease is due to venous return and diastolic filling time interaction. Thus, Faulkner concluded that myocardial contractility only plays a secondary role.

The volume of oxygen leaving the heart, according to Bergh et al. (17) is the most important factor in limiting V02max. Katz (53) reported extrinsic and intrinsic neurogenic factors control the heart's rate and contractility and therefore, limit aerobic capacity. Exercise which involves small muscle groups may be limited by peripheral factors such as enzyme activist and local muscle blood flow (54). The V02max in these cases may not always give a clear picture of the heart's function as previously stated.

Maximal oxygen consumption can be expressed in different units and thus given a different meaning. The value of L/min was considered by Astrand (9) to be a measurement of total oxygen transport which "is correlated to the cardiac output, the myocardial oxygen consumption, and blood flow". The value of ml/kg·min "serves as a prediction of the subject's ability to move his body, as in walking or running". When comparing individuals of various sizes, the relative form of ml/kg·min should be used.

Many methods for assessing physical fitness have been developed and recorded in the literature (9, 67, 90, 89). The maximal oxygen consumption of an individual is an objective measure of cardiovascular fitness (26, 28, 88), (Appendix A). Taylor et al. (88) found maximal oxygen uptake during work a reliable criterion for assessing overall capacity of an individual to perform aerobic work. Therefore, a person with a high level of fitness will be able to perform physical work more efficiently than one who is unfit (63).

Tests Which Directly Measure Maximal Oxygen Consumption

It has been established that V02max may be used as a determinant of physical fitness (26, 28, 88). The testing of V02max involves a direct measurement of oxygen consumption during physical work. The workload increases until the subject is unable to continue due to exhaustion.

For the test to be maximal, Astrand (12) used the following requirements: large muscle groups must be engaged in the activity, the workload must be measureable and reproducable, test conditions must be such that the results are comparable and repeatable, all healthy individuals must be able to tolerate the test, and the skill required to perform the task should be uniform to the population. The gases collected during the testing should also meet certain criteria. The respiratory exchange ratio should be greater than 1.00, and a leveling should be reached of oxygen consumed (within .15 L/min or 2 ml/kg·min in last three bags). Because 02 uptake increases linearly with increasing workloads up to maximum V02, a plateau of 02 uptake with an increasing workload is a sure sign that the subject has achieved maximum (89). Another determinant of maximal oxygen uptake is the HR reaching a maximal value. Astrand (6) used the level of lactate in the blood to establish an oxygen intake plateau.

Tests to measure V02max vary within the literature (9, 28, 69). Two types of tests which are generally used involve the subject working to exhaustion on a constant workload and the test depending on the duration or the workload gradually increasing until the subject became exhausted (67). Several investigators have found the treadmill and bicycle to be the most acceptable method of measuring individual V02max (41, 44, 52). The use of the treadmill in maximal testing has been developed by several researchers including: Taylor (88), Bruce (20), Balke (15), and Astrand (9). Astrand (9) has also used the bicycle ergometer for much of the research involved in oxygen consumption. Other modes which have been used to elicit V02max are arm cranking (36, 39), twelve minute run (9), swimming (9), and cross-country skiing (9). Most recently the use of combined arm and leg cranking has been under investigation (19, 81).

Comparisons of Results Elicited by Various Testing Modalities

Comparison of Bicycle to Treadmill

As previously stated, the bicycle and the treadmill are the two most popular testing modes for measuring VO2max (40, 43, 51). The bicycle has the following advantages: portability, regulated workload, safe, less expensive when compared to the treadmill, the task is easy to learn, and the task is non-weight bearing (62, 102). Two disadvantages of the bicycle include the need for frequent calibration and the problem of local muscle fatigue with heavy workloads. The advantages of the treadmill are: the work rate is constant, the activity is familiar to people of all ages, and it is relatively easy to obtain clear and accurate physiological measurements (102).

The disadvantages of the treadmill are similar to many of the advantages of the bicycle. They include lack of portability, expense, somewhat of a danger to the subject, weight dependent (which will change workload for the same stress test), and instrumentation may be difficult (85). In the case that the subject is unable to walk long distances, the bicycle is the ideal mode for testing (85).

The treadmill and bicycle have been proven beneficial in improving cardiovascular fitness (71). Astrand and Saltin (14) in 1961 stated, "For all practical purposes, the maximal oxygen intake is approximately the same whether it is measured while running on a treadmill or during cross-country skiing, or bicycling".

However, in much of the literature the treadmill appeared to elicit a higher V02max than the bicycle. Hermansen et al. (45) found a 6% increase in V02max with the treadmill, Astrand and Saltin (12) -5%, Glassford et al. (41) -8%, Faulkner et al. (37) -11%, Kamon and Pandolf (5) -6% for males and 3.6% for females, McArdle et al. (60) -10.2% to 11.2%, Niederberger et al. (70) -8%, Wicks et al. (98) -17%, and McKay and Bannister (62) -7.58%. Several others found an increase also (48, 65, 66).

Other physiological differences between treadmill and bicycle have been researched in the literature. Bergh et al. (17) found the maximal HR was higher with treadmill exercise. Miyarmura and Honda (67) also found an increase in HR with the treadmill along with a greater A-V02 difference with no change in SV. Hermansen (44) also reported an increase in mean arterial pressure (MAP) which reflected a higher peripheral resistance.

To obtain maximal value when using the bicycle ergometer, Astrand (12) stated that one must motivate the subject to push past the point of leg fatigue. He also suggested, "The bicycle seat should be high enough and the subject should be positioned almost vertically above the pedals" to simulate the standing posture. The authors reported increasing pedal frequency to lighten the workload on the legs (62, 65).

Comparison of Arm Work to Leg Work

The values attained on the arm ergometer as compared to the leg ergometer are much lower when comparing oxygen uptake at maximal workload (44). Astrand (14) found arm exercise to be 70% of V02max attained in leg exercise. The difference in V02max between arm and leg ergometry may reflect the relative degree of conditioning between the upper and lower extremities (75). Oxidative capacity, muscle mass, or a combination of the two could affect the degree of condition (75). Seals and Mullin (80) found that upper body trained athletes attained higher V02max's than the non-upper body athletes when using the arm ergometer. Fardy (36) took into consideration segment volume and found arm V02max to be greater than leg V02max. Other literature pointed toward different recruitment patterns of motor units (61) and distribution of fast and slow twitch muscle fibers in an individual's arms and legs (22, 24) as reasons for discrepancy in aerobic capacity. The different muscle fiber theory has been refuted by Gollnick (27) who has found comparible distributions of muscle fibers in the deltoid and vastus lateralis muscles of an individual.

During arm work, literature showed an increase in HR, ventilation, blood pressure (bp), and Q for a given oxygen uptake as compared to leg work (17, 23). These physiological responses appear to reflect an increase in sympathetic tone during arm exercise associated with increase contractility of the myocardium. An increase in blood pressure is due to the greater muscle mass utilized for stabilization and thus a greater peripheral vascular resistance (18). Collett (23) found an increase in Q with arm work, however, Asmussen (2) saw no difference in Q between arm and leg work. Increase in ventilation is thought to be due to a greater precent of energy derived from anaerobic glycosis which results in a respiratory alkalosis (61).

For those individuals who are unable to train by conventional methods such as running or walking due to paralysis, amputation, or debilitating disease, arm ergometer appears to be the preferred exercise mode (39). Many studies involving spinal cord injured subjects have found high success by training with the arm ergometer (39, 74). V02max and arm work increased significantly, along with a decrease in HR and percent body fat. These findings refute the idea that a large muscle mass is needed to develop cardiovascular fitness (74). Zwiren et al. (104) learned that conditioning upper limbs and trunk muscles compensated for the lack of use of a large muscle mass.

Studies using cardiac patients also have shown arm work to be a satisfactory alternative diagnostic test method with respect to myocardial ischemia (79). The upper extremities respond to exercise conditioning in the same qualitative and quantitative manner as do the legs (74). Its use has been extended to include rehabilitation (36, 79). The principal finding, that arm work is greater than leg work at a given submaximal load, needs to be taken into consideration when prescribing exercise programs utilizing the arm ergometer (36).

Women are participating more in activities which require upper extremity strength. Previous research indicates that there is a disproportionate difference between men and women in arm versus leg strength (28). Vander et al. (92) found that even though women have lower arm V02max then men, it appeared their aerobic capacity for arm work is not disproportionately inferior to men's.

Comparison of Combined Arm and Leg Work to the Treadmill

In recent studies, the use of combined arm and leg exercise has been used for the attainment of maximal oxygen consumption (42). Astrand (13), in 1954, found the treadmill value of V02max to be higher than the combination of arm and leg work. He concluded at that time, "The important determinant of maximal oxygen uptake is the mass of muscle employed in performing the task used to elicit Max V02". Hagen et al. (43) presumed the higher value on the treadmill was due to the fact that the body weight must be lifted during the work.

A study done by Seals and Mullin (80) found the opposite, a greater V02max obtained with the combined arm and leg work. Bergh et al. (17) studied the effect of combined arm and leg exercise on V02max. The arm and leg exercise was performed in four ways; the arms doing 10%, 20%, 30% and 40% of the same total workload. Bergh pointed out that the highest oxygen uptake attainable depends on the ratio between arm work and total rate of work. He concluded to get optimal V02max readings, 20% of maximal work should be performed by the arms. Secher (80) found similar values of V02max between combined arm and leg exercise and treadmill. He assumed the similarity was due to similar muscle mass involvement. Gleser (42) showed that adding arm work to already existing maximal leg work increased V02max by an average of 10%; the increase due to added muscle mass. Reybrouck (74) stated the difference between V02max attained with combined arm and leg and leg ergometry appeared to be the degree to which the subject was conditioned for leg ergometry.

Astrand and Saltin (14) in 1961, found the difference in oxygen uptake in combined exercise to be much smaller than expected with the use of such a large muscle mass. At this time, they proposed the difference to be caused by the limitation of the heart's capacity. Secher (81) found, with the addition of arm work to heavy leg work, that there was a reduction in blood flow as well as oxygen uptake in the exercising legs. He believed an increase in sympathetic activity occurred with the combination of exercise which counteracted vasodilation and immediate vasoconstruction even in muscle performing severe exercise, thus supporting the peripheral circulatory limitation theory.

Limitations of Maximal Oxygen Consumption

The direct measurement of maximal oxygen consumption to determine physical fitness has limitations. First of all, personnel need to be trained and competent in the procedure, especially for those subjects over 35 years old (12). The equipment used for analyzing the gas exchange is expensive and intricate (27). A third limitation is the cooperation and motivation of the subject (27). Those not accustomed to vigorous exercise many times fear the pain which accompanies physical stress. It is not always easy to decide whether or not peak values for oxygen uptake have been reached because the subject is in control of stopping the test (12).

The determination of V02max is a time-consuming procedure for both the subject and investigator and for this reason, it is not commonly employed in the study of large groups of people (92). To obtain a reliable measure of V02max, the subject must be pushed beyond the point at which maximal rate of oxygen occurs (27). For the elderly, cardiac, and sedentary individual this test may be dangerous to their health (27). It has been reported that at least one patient has died on the treadmill during maximal effort (27).

Prediction of Maximal Oxygen Intake

During exercise of submaximal intensity, HR and ventilation rate increases approximately in proportion to increase in oxygen uptake. Taylor (88) reported that heart rate, ventilation, and blood lactate responses to submaximal testing had a high enough correlation to predict maximal oxygen consumption. Consequently, numerous attempts have been made to predict V02max from HR, ventilation rate, and other variables during standardized submaximal exercise loads (9, 27). Astrand (9) reported, "No objective measurements made on resting individuals will reveal their capacity for physical work or their maximal aerobic power", as will the submax test. A low heart rate and large heart size may indicate high aerobic power but, on the other hand, it may be a symptom of disease. Advantages of submaximal testing include being able to test patients with cardiovascular disease and being able to determine training programs for the effect of improving cardiovascular capacity (9).

Issekutz (49) looked at the respiratory quotient (RQ) during submaximal testing as a measure of aerobic capacity. This theory was based on observations that "expired CO2 during short intense work efforts as derived from the body bicarbonate pool as a result of accumulation of lactic acid during exercise" (9). Issekutz (49) stated that RQ "directly reflects fractional increments of anaerobiasis in meeting increased energy costs". The advantage to this method was its independence from sex and age. However, it was technically more complicated and certain requirements had to be fulfilled for the data to be reliable (48).

Rowell (75) found no relationship between RQ and VO2 when using well-trained athletes except at very high work intensities. Shepard (82) looked at the respiratory exchange ratio (RER) during submaximal exercise and found it to be a good measure of prediction, but lacked standardization. Other researchers have attempted to increase on submaximal rate regression models by developing multiple regression models to improve predicted values (37, 43, 62, 94). Another predictor of VO2 used in the literature is the submaximal heart rate response to a standard level of work (9, 28, 61).

Heart Rate - Maximal Oxygen Consumption Relationship

The authors of the research review the relationship between HR and VO2max (9, 28, 32). There is a linear relationship between oxygen intake and workload (9, 16, 29). Astrand (9) reported, "The simplest and most extensively applied way of testing the circulatory functional capacity is to determine the heart rate during or after exercise". DeVries (28) agreed with the measurement of HR during work, but that use of recovery HR had less of a predictive value. Each individual has a defineable maximal HR which is highly reproducable from test to test (102). Thus, the VO2max is predicted from submaximal HR by extrapolating this value to the assumed maximal heart rate. Sinning (84) reported this method was possible because the max HR and max VO2 were reached simultaneously.

Wyndham (cited by DeVries) (29) found when plotting VO2 against HR and workload, that the two variables approached asymptotes at different rates. When the maximal HR was attained, work could increase with no increase in heart rate. This further increase in workload produces an oxygen debt in which additional energy to meet oxygen demands is produced via anaerobic glycolosis (84). Davis (27) stated, "The major limitation to direct prediction of VO2max from the heart rate and VO2 data would seem to be the asymptomatic nature of the HR/VO2 curve".

Age Correction Factor

As in individual ages, maximal heart rate decreases along with a reduction in mechanical efficiency (9). This decline in certain physiological factors is believed to be a result of biological aging and a sedentary life style (100). Sinning (84) stated that the maximal HR is more closely related to age than any other factor, however, there are considerable variations within any given age group.

Age correction factors have been established by Astrand (7) in 1960 and by VonDobeln (94) in 1967 to accommodate for the decreased HR with age, (Appendix B). Cink and Thomas (21) found the Astrand age correction to be more accurate when classifying individuals in fitness categories than was the VonDobeln. In prediction of V02max either factor seems adequate. Astrand, P-O (7) reported the maximal heart rate to be about the same for males and females, however, when performing submaximal work, the females had a considerable higher HR than the male. I. Astrand (4) in 1973, found a large method error when reexamining the original age correction and concluded that separate age correction factors should be used between sexes. Londeree et al. (55) obtained statistical data on over 23,000 subjects from 5 to 81 years to reduce confusion on effects of age on maximal exercise HR. Equations were proposed which included independent variables such as age, sex, fitness level, exercise protocol and race.

Submaximal Tests as Predictors of Maximal Oxygen Intake

Submaximal heart response to work has been used in tests with the treadmill, bicycle and steps (12). Three advantages of submaximal testing are as follows: motivation can be eliminated as a factor in physical fitness screening, older subjects and unconditioned individuals can be tested with less danger, and one can estimate the reserve power of the cardiovascular system and evaluate the response of the system to work overload, thus establish a functional capacity value (28). Astrand (12) reported no difference in HR at a given oxygen uptake at submaximal workload independent of mode.

Leg Testing

The submaximal bicycle ergometer test has been used with a variety of procedures to predict V02max (12, 28). Astrand (8) reported the bicycle exercise to be a "suitable work form, at a given submaximal load 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". Wahlund (13) found a fairly constant mechanical efficiency when subjects were working on the bicycle ergometer. Oxygen intake could be indirectly estimated from workload within ±8% in two-thirds of the cases.

Hermansen (44) reported a higher mean HR value attained on the cycle as compared to the treadmill. The difference he suggested, was the result of smaller muscle mass involvement with bicycle riding. With the use of the bicycle ergometer in submaximal testing, Astrand (9) suggested a submaximal work level lasting at least four minutes in length. This time factor was established so that the respiration and circulation could reach a steady state, the point where oxygen demand equals oxygen uptake. At that time, the heart rate and ventilatory system have attained stability. Taylor (88) reported the intensity and duration cannot exceed the capacity of the poorest subject. Protocols using the submax bicycle ergometer vary with respect to workload (9), seat height (85), pedal speed (61, 64), and continuous versus discontinuous (96).

Arm Testing

Arm testing at submaximal loads has also been researched in the literature (14, 44, 75). Arm position according to Davies (27) affected anaerobic capacity. Pendergast (72) reported a decrease in V02max with the arms positioned above heart level. However, a study by Cummins and Gladden (25) cited no significant difference in the response to submaximal arm cycling with the arm position above, at, or below the heart level. Numerous studies have shown that at a given submaximal workload, HR, BP, V02, RER, and lactate production were significantly greater during arm work (2, 14, 44, 74). With a greater oxygen cost the mechanical efficiency is less when using the arm ergometer (39). Anaerobic threshold expressed as a % of V02max was lower during arm exercise compared to leg. Asmussen and Henningsen (2) therefore concluded that it was not possible to estimate total aerobic power from experiments utilizing arm work.

Combined Arm and Leg Testing

Little research has focused on the affect of submaximal combined arm and leg exercise. Hagan (43) found HR, V02, VC02, and VE similar in leg and combined arm and leg work at equivalent submaximal workloads on an air braked ergometer. Reybrouck et al. (74) studied the effect of arm, leg and combined arm-leg ergometry on the V02, $\dot{Q}$, AT, and ventilation. At submaximum work intensities, V02 was not significantly different in the three tasks, but differences were observed in HR, ventilation and Q.

1) The pulse rate during submaximal work increase approximately rectilinearly with the oxygen uptake.
2) The submaximal pulse rate not lower than 125 bpm are used for the prediction, and
3) The pulse rate of the subject can reach a maximal value of 195 bpm (SD = ±10) when cycling or walking.

Separate scales were used for males and females along with age correction factors. Pedal frequency was set at 50 rpm and initial workloads were to be set at 600 kpm/min for females that were well trained and 900 kpm/min for well trained males. Modified loads were determined for less fit individuals. A steady state HR should be reached by the fifth and sixth minute. The mean value of the HR between the last two minutes should be between 125 and 170 bpm with a difference no greater than 5 bpm. It was important for the fitness level to be accurately assessed in order for the individual to reach steady state during the 5th or 6th minute. Astrand (7) reported a correlation coefficient of .718 for males and .653 for females with a standard deviation of 15.92 and 16.10 respectively with use of the modified nomogram. Appendix C-F present the modified nomogram along with a table giving predicted values and conversion of L/min. to ml/kg·min.

Validity and Reliability of the Modified Nomogram

The use of the Astrand-Rhyming Nomogram for practical purposes using the bicycle ergometer has been reviewed in the literature (28, 41). Glassford (41) reported the Astrand-Rhyming test correlated to maximal data as well as did an actual second maximal test. Although the Astrand-Rhyming test can provide a close approximation of V02max, it is subject to prediction error of around 10% (28). DeVries (28) found a validity coefficient of .736 for the nomogram.

The accuracy of the nomogram according to Astrand (7) can be enhanced by using higher workloads. Terry (91) developed a nomogram, which predetermined workload, to be used with the Astrand-Rhyming (A-R) test. The subject was tested at 600 kpm/min for one minute. The HR achieved and the subject's body weight were used to calculate the appropriate exercise load for the test.

Davies (26) showed that the A-R nomogram consistently underestimated V02max. He reported that if one was to use the nomogram that a heart rate near 165 bpm was optimal for predicting aerobic capacity. The higher intensities produced intra-individual variation at lower intensities ranged from 3 to 8%.

Wyndham (89) criticized the Astrand nomogram because it was based on the rectilinear relationship between HR and oxygen consumption. Wyndham demonstrated that the relationship between the variables concerned was asymptotic. Astrand (7) responded to Wyndham by stating, "Their criticism is not valid. It is not the premise of the nomogram that the heart rate is a rectilinear function of oxygen uptake throughout the range of values. It was constructed empirically from data on heart rate and oxygen uptake during submaximal work and maximal oxygen uptake actually measured".

Glassford (41) stated that the intra-individual variability of the HR was due to general fatigue of the legs with only moderate stress placed on the upper body.

Asmussen and Hemmingsen (2) determined resting HR and work HR were needed to obtain more reliable extrapolated data. However, according to Margaria (58) the HR at rest has a rather high variability and found reduction of error by using two submaximal heart rate values.

VonDobelin (95) found an 8.4% error with the introduction of an age correction factor. Astrand (90) reported a correlation coefficient of .709 without the age correction and .92 correlation with the factor added. Cink and Thomas (21) found the Astrand age correction factor adequate when determining fitness classification (r=.76). With regards to fitness level, Astrand (12) reported untrained individuals would be underestimated and well trained subjects overestimated with use of the A-R nomogram. Reliability of the nomogram in predicting oxygen uptake was reported by Day (100) to be .80 and by Dahlstrom (100) to be .83. Williams (100) tested reliability of the A-R nomogram on 31 females and found reliability of a single trial to be .64, reliability of three trials over three days to be .80, and reliability of six trials estimated above .90. She concluded single trials on several days are better than multiple trials on each day.

Accuracy of the Nomogram in Predicting, Using Various Modes

Whether the submaximal bicycle test is compared to a maximal bicycle test or to another mode makes a difference in the validity measurement (17). Predictions of V02max from submaximal bicycle test when compared to actual maximal test on a treadmill vary in degree of accuracy as reported earlier in this review (12, 28).

Astrand and Saltin (14) originally stated that no significant difference existed between bicycle and treadmill when tested V02max on young, healthy subjects. However, much of the literature disproved this statement (37, 59, 41).

Teraslinna (90) used a submaximal bicycle test prediction and compared max V02 to a max bicycle test. The author found a 0.92 correlation between maximal oxygen uptake and the predicted value. Glassford (41) in a similar study reported a correlation of 0.65 in L/min and concluded that the A-R test was a good predictor of V02max.

Bonen et al. (21) suggested that homogeneous modes correlated the best. Taylor (88) found maximal oxygen consumption only maximal for the specified working condition.

Factors Influencing Predicted Value of Maximal Oxygen Consumption

Adams (1) stated that neither sex or age have a significant effect upon the gross energy expenditure of riding a bicycle. Other literature (12) pointed out that if young and old are included in the same study, the circulatory capacity of the older subjects will be overestimated compared to the young. Astrand (12) reported with the introduction of an age correlation factor that the standard deviation for max HR within an age group was ±10 bpm, therefore, 50% of the subjects would be overestimated and the remainder underestimated.

Maximal HR decreases with age, but within the same age group there is a wide variation (8). If the maximal HR of an individual is higher than average, the technique would underestimate the individual and vice-versa (84). As mentioned earlier, the difference in mode from predicted value to actual value influences the accuracy of the test.

Astrand (9) found a linear relationship between HR and V02. However, in some cases, the oxygen uptake increases relatively more than HR as workload increases (26).

When oxygen uptake is predicted from workload it is assumed that the mechanical efficiency is constant. However, the literature reported a ±6% variance in mechanical efficiency with the bicycle ergometer (26).

Other factors which influence accuracy of the procedure include environmental conditions such as excessive heat or cold, smoking or eating before the test is given (12). Taylor (88) found at any given level of submaximal work the pulse rate can vary independently of the oxygen uptake, but directly with the emotional state or degree of excitement.

A few other factors influencing the predicted value of V02 are physical fitness (12), total circulating hemoglobin (15), degree of hydration of the subject (28), and hydrostatic induced changes resulting from prolonged standing (2).

SUMMARY

The maximal oxygen consumption is the maximal amount of oxygen that can be taken up by the blood and delivered to the cells (75). The measurement is an objective indicator of cardiovascular fitness (8, 9, 66).

Various modes of maximal testing have been examined in the literature (9, 28, 68). The two most popular methods of testing are the bicycle ergometer and the treadmill (40). The treadmill is the mode which consistently elicits a higher V02max. Recently, the use of arm and leg combined exercise has been introduced in the literature (19, 81).

Limitations of maximal stress testing include the need for trained personnel, expensive and intricate equipment, a possible hazard taken by the subject, and a great deal of time involved (12, 27).

Prediction of V02max has been studied with various physiological variables used as predictors (9, 82). Issekutz (49) found the RQ to be a good determinant of V02max. Heart rate appears to be the most popular factor used in determining maximal oxygen consumption (9, 28). Literature showed a linear relationship between HR and V02. Others felt the relationship was asymptomatic (29). Age correction factors have been introduced in the literature to accommodate for the decline in max HR with aging (7, 92).

Submaximal testing as a predictor of V02max has been supported in the readings (9, 12, 44). Different modes including bicycle and arm ergometry are found (14, 44, 74). The use of combined arm and leg submaximal testing is scarce.

The Astrand-Rhyming Nomogram was developed to predict V02max from the heart rate response to a submaximal workload (13). The nomogram according to Astrand (13) was valid for tests using the treadmill, bicycle, or step test. Much of the more recent literature disproves this statement (26). A higher workload along with the use of an age correction factor seemed to predict the most accurate values (26, 94). According to Williams (100) reliability could be further enhanced with multiple trials distributed throughout several days.

It appeared from the review, that there is a variation in physiological values when using different modes between maximal and submaximal testing (89). Factors which influence the predicted value of V02max include age, maximal HR, relationship between HR and V02, and external and internal environmental conditions (8, 9, 12).

CHAPTER THREE

Introduction

The purpose of this study was to examine the relationship between a combined arm and leg submaximal test to maximal oxygen consumption. Experimental research was performed to correlate the data.

PROCEDURE

Research Design

Thirty females, aged 18 to 31, from the University of Kansas, volunteered for this study. The testing took place from May 1, 1984 to May 20, 1984.

Each subject was tested in the Exercise Physiology Lab at the University of Kansas. Prior to testing procedures, the subjects were briefed on each procedure used for this particular study and habituated to the equipment to be used.

The subjects reported to the lab on three separate test days which occurred approximately at the same time of the day with at least 24 hours between test days. One test day included the performance of the Astrand-Rhyming submaximal bicycle test. A maximal bicycle ergometer test was given five minutes following the submaximal test. A second test day involved the submaximal arm and leg combined exercise bout followed by a five minute rest.

The maximal combined arm and leg procedure then proceeded from the rest period. The Astrand treadmill test was given on a third test day to determine V02max in L/min and ml/kg·min. The subjects were randomly put into three groups with the order of the tests varying between the three groups.

The Pearson product moment correlation and the standard error of estimate were used as a means to determine the correlation between submaximal tests and the V02max measurement. A multiple regression equation was designed for the submaximal combined arm and leg test for predicting values of maximal oxygen consumption.

Selection of Sample

Thirty female subjects, 18 to 31 years of age, volunteered to participate in this study. The majority of the subjects were students at the University of Kansas during the Spring of 1984. The subject signed a consent form and their fitness was evaluated from a questionnaire (see Appendix G). A trained subject was one who earned 30 Cooper points or more a week. An active individual exercised periodically and an untrained individual was one who was sedentary. Each subject was to continue with her normal activity and exercise routine aside from the testing session. The physical characteristics of the subjects are shown in Table 1.

Equipment Used

Subjects were weighed on an electronic scale (Toledo, model 8134 and 2084) with accuracy to the nearest 0.05 kilograms.

Table 1

Physical Characteristics of Subjects

Subjects	Age (years)	Weight (kilograms)	Height (centimeter)	Fitness Level
1	24	48.85	164	T
2	20	53.45	164	T
3	24	66.55	165	T
4	23	80.45	185	T
5	21	65.85	169	T
6	23	65.35	169	T
7	18	67.00	172	U
8	24	81.55	174	U
9	21	64.20	177	A
10	20	67.80	172	A
11	19	53.40	162	U
12	31	52.90	164	A
13	24	68.55	160	T
14	21	57.20	169	A
15	22	55.05	164	T
16	22	60.25	174	U
17	30	50.90	167	U
18	24	57.75	159	T
19	27	59.45	163	A
20	23	50.40	154	A

Table 1 (cont'd)

Subjects	Age (years)	Weight (kilograms)	Height (centimeter)	Fitness Level
21	28	70.25	177	T
22	22	69.15	161	U
23	22	65.00	169	T
24	24	82.00	170	U
25	21	64.30	177	A
26	27	52.80	160	A
27	22	57.40	164	A
28	20	54.05	163	A
29	24	57.85	159	T
30	27	60.00	163	A
Mean	23	62.05	167	
S.D.	3	9.15	7	

T = trained

A = active

U = untrained

The submaximal and maximal bicycle tests were performed on a Monark bicycle ergometer (model 868). The arm cranking tests were performed on a Monark bicycle ergometer placed on a platform chest level to the subject (Appendix H). Calibration of both ergometers was performed prior to testing.

The maximal treadmill test was performed on a Quinton Motor Driven Treadmill (model 24-72). The breathing apparatus was a Daniels-type one-way valve with mouthpiece, which was held in place by an adjustable head set. A spring-like noseclip (Collins) was fastened to the subject's nose to prevent exhalation through the nose. The breathing valve and mouthpiece were connected to 73 cm length of internally corrugated plastic hose. The hose was connected to a series of meterological balloons. A three-way high velocity, low resistance valve (Collins) controlled the flow of the air.

The heart rate was monitored with a Quinton ECG Monitor System (model 621 B). Sanborn Redux Electrode Paste was used to cleanse the skin followed by application of NDM diaphoretic electrodes. The Lead II set up was used.

Expired air was analyzed using the Applied Electrochemistry Oxygen Analyzer (model S-3A), flow control (S-3A), and oxygen sensor (W-22M). For CO2 analysis the Beckman Medical Gas Analyzer (model LB-2) was used. Calibration of the analyzers was performed with gas from the Burnidge Oxygen Supply Co., Kansas City, Missouri.

The calibration gas contained 16.96% 02 and 3.93% CO2. A Parkinson Cowan CD-4 dry gas flowmeter with digital readout was used to measure the total volume of expired air of each subject. The ambient temperature and barometric pressure were measured using a Prince C469 thermometer and barameter. Gas temperature was measured with an expired gas thermometer, Yellow Springs (model 41TA).

Pedalling tempo for the bicycle tests was kept constant with a Franz Electric Metronome (model LM-FB-4). A Lafayette timer (model 53011) was used to time the bicycle ergometer test.

Personnel Used

Three investigators served as laboratory personnel. Three laboratory personnel were present during all tests. During the treadmill test, one investigator was responsible for weighing the subject, measuring the subject's height, preparing the subject for the test, and spotting the subject while on the treadmill; a second investigator was responsible for increasing the speed and grade of the treadmill, watching the ECG monitor, the time; and the third investigator was responsible for collecting the expired air for gas analysis.

During the submaximal and maximal leg and combined exercise test on the bicycle, one investigator perpared the subject for testing and monitored and recorded HR; the second investigator adjusted workload and monitored the ECG; and the third investigator collected expired air during the tests.

A pilot study was performed one week prior to testing. At this time the personnel were briefed on their specific duties and reliability was secured.

Measurement Procedures

Preliminary Procedures

Instructions for the subjects were explained in detail (Appendix I, J), and each subject signed a consent form (Appendix K) prior to testing. All subjects were scheduled to report to the Exercise Physiology Lab on the K.U. campus. Subjects were asked to wear suitable running attire including comfortable shorts, top, socks and shoes.

Subjects were randomly divided into three groups of ten (A, B, C) (see Table 2) Group A performed the maximal treadmill test on the first test day, performed the bicycle test on a second test day, and finally performed the combined procedure on a third test day. Group B performed the bicycle test at the first setting, followed by the combined procedure on a second test day, and on the third test day, performed the treadmill test. Group C performed the combined procedure first, secondly the treadmill, and then the bicycle test on three separate test days. All tests were performed approximately the same time of day with 24-48 hours between procedures.

Table 2

Order of Tests

TEST ORDER BY DAY		TREADMILL (max)	BICYCLE (submax, max)	COMBINED (submax, max)
Day 1	GROUP	A	B	C
Day 2		C	A	B
Day 3		B	C	A

Prior to treadmill testing, each subject practiced mounting, walking, and jogging on the treadmill. The speed was varied in accordance to the subject. Prior to the bicycle test, the subject was allowed to pedal the ergometer at different workloads. The subjects were also habituated to the combined arm and leg set up prior to testing. The habituation period was used to increase the reliability value which according to Williams (100), increases with the greater number of times the test is administered.

The subjects were weighed immediately prior to each test. The scale used was accurate to the nearest 0.05 kg. Height was taken from a scale mounted on the wall to the nearest 0.5 cm.

A Lead II electrode placement set up was used for heart monitoring. The skin was prepped with Sanborn Electrode Paste and alcohol, followed by application of the electrodes. A Lead II set up is diagrammed in Appendix L.

The Submaximal Bicycle Ergometer Test

The Astrand-Rhyming Modified Bicycle ergometer test was used as described by Astrand and Rodahl (12), Astrand and Rhyming (13), and Glassford (41).

Each subject performed the test on a Monark bicycle. Handlebars were adjusted to suit the subject. The saddle height was set to allow the subject's knee to bend slightly when the ball of the foot touched the pedal and the leg was in a down position. The subjects pedalled at a rate of 50 complete revolutions per minute with the aid of a calibrated metronome set at 100 bpm.

The initial workload was set on the basis of fitness and activity level of each subject. Trained individuals were those who performed 30 Cooper points or more a week. Active (moderately trained) individuals were considered those who were active, but performed less than 30 Cooper points a week. Untrained individuals performed little to no activity. For the untrained and active subjects, the workload was set at 300 kpm/min. For the well-trained, the workload was set at 450 kpm/min.

The subjects began the test at the predetermined workload. The heart rate was monitored and recorded during the last ten seconds of every minute. If the HR was greater or equal to 70% max HR, the load was considered adequate and the test was terminated after six minutes (83). If after three minutes the HR was below 110 bpm, the load was increased by 150 kpm/min. A steady state must have been reached before the test was discontinued. The criteria involved a HR greater than 70% MHR with a difference of five beats or less between the fifth and sixth minute. The test was continued one or more minutes until the requirements had been met, (Appendix M).

Table 3

Astrand-Rhyming Test

SPEED:	Constant at 50 rpm
WORKLOAD:	300 kpm/min for untrained and active
	450 kpm/min for well-trained
TIME:	Steady state reached between 5th and 6th minute with HR greater or equal to 70% max HR

Heart rate measurements were taken by measuring in mm., three cycles of QRS peak to QRS peak. Paper speed was set at 25 mm. per second. The distance between peaks was divided by 4,500 and HR in bpm derived. Expired air was collected every 30 seconds. After completing the submaximal bicycle ergometer test, each subject rested on the bicycle for five minutes, (Appendix N).

The Maximal Bicycle Ergometer Test

The maximal bicycle ergometer test was a modified version of the one described by Teraslinna et al. (90). The time between submaximal and maximal test was used to increase metronome tempo to 120 bpm and therefore, increase pedalling speed to 60 rpm. The headpiece and mouthpiece were fitted to the subject and the gas collection system was reconnected.

With the completion of the five minute rest, the subject began pedalling at a frequency of 60 rpm with the workload set at 0 kpm/min. Workload was increased to 150 kpm/min and the timer started with the subject pedalling. Workload was set at 150 kpm/min for the first two minutes, and was increased 150 kpm/min for every minute thereafter until the subject was exhausted. Subjects were asked to signal one minute prior to complete exhaustion.

Table 4

Maximal Bicycle Ergometer Test

SPEED:	Constant at 60 rpm	
WORKLOAD:	0-2 minutes	150 kpm/min
	2-3 minutes	increased by 150 kpm
	3-4 minutes	increased by 150 kpm
	↓	↓
	exhaustion	exhaustion

Expired air was collected every 30 seconds and HR was continually monitored throughout the test. Testing was stopped if the subject became dyspnic, pallor, or presented with chest pain or radiating pain to the arms or jaws. Any ECG changes were noted and if ST changes or arrhythmias were present, the test was immediately stopped. Otherwise, the subject terminated the test after complete exhaustion. After termination of the maximal test, the subject continued pedalling with no resistance until the HR lowered to 120 bpm.

The gas collected from the last three bags was analyzed for %O2, %CO2, total volume and gas temperature. Maximal oxygen intake was calculated in L/min and ml/kg·min (Appendix O). Criteria for achieving maximal included RER greater than 1.1; maximal HR was attained (based on Londeree's (55) equation):

$$\text{PMHR} = 196.7 + 1.986 \times E + 1.490 \times F4 + 3.730 \times F3 + 4.036 \times F2 - 0.0006 \times A4 - 0.542 \times A2$$

PMHR = Predicted maximal heart rate
C = Cross section
E = 1 if using the treadmill
F4 = 1 if trained, otherwise F4 = 0
F3 = 1 if active, otherwise F3 = 0
F2 = 1 if untrained, otherwise F2 = 0
A^2 = $(\text{age})^2$
A4 = age 4

A third criteria was a leveling of oxygen consumption for three consecutive bags (a difference equal or below 2 ml/kg·min or .2 L/min).

The Submaximal and Maximal Arm and Leg Test

Submaximal and maximal combined arm and leg test preparation was the same as the maximal bicycle test preparation. A Monark bicycle was used to exercise the upper arms. The bicycle was placed atop a platform which reached check level when the subject was sitting on a second bicycle ergometer. The axis of the cranking arm was in line with the glenohumeral joint (Appendix H).

Workload for the legs and arms added were equivalent to the workload used during the submaximal and maximal bicycle test. The arm work was 20-25% that of the total workload (17).

The submaximal procedure and criteria was set the same as the Astrand-Rhyming bicycle ergometer test. There was a five minute period prior to the start of the maximal test.

Table 5

Combined Arm and Leg Submaximal Test

SPEED:	Constant at 50 rpm
WORKLOAD:	300 kpm/min for untrained and active
	Arms = 20-25% total workload
	Legs = 225 kpm/min
	Arms = 75 kpm/min
	450 kpm/min for trained
	Legs = 350 kpm/min
	Arms = 100 kpm/min
TIME:	Steady state reached during the 5th and 6th minute with HR greater or equal to 70% MHR

The maximal test procedure and criteria was identical to the maximal bicycle test described as far as workload and time were concerned. Exhaustion was indicated by a drop in rpm below the required level of 60 rpm. The HR and expired air was measured during both submaximal and maximal tests.

Table 6

Maximal Combined Test

SPEED:			
WORKLOAD:	0-2 minutes	150 kpm/min Legs = 150 Arms = 0	
	2-3 minutes	increased by 150 to 300 Legs = 225 Arms = 75	300 kpm/min
	3-4 minutes	increased by 150 to 450 Legs = 350 Arms = 100	450 kpm/min
	↓ exhaustion	↓ exhaustion	

The Maximal Treadmill Test

The protocol described by Astrand (12) was followed for the maximal treadmill test. Each subject was prepped with electrodes as described previously for the bicycle tests. The HR was recorded each minute and during recovery. A short warmup (2-3 minutes) at the beginning testing speed and grade was performed on the treadmill prior to the maximal test.

For the maximal test, speed was constant with the range being from 5.25 - 7.0 mph depending on the subject. Grade and speed were estimated from the fitness questionnaire and Table (12). Grade was increased after three minutes (see Table 7). Maximal HR was reached within 3-8 minutes of the test. The subject continued the exercise until subjective fatigue was reached. A cool down followed the maximal performance. Criteria for attaining a maximal performance was the same as for the maximal bicycle test.

Table 7

Astrand Maximal Treadmill Test

Predicted VO2max (ml/kg·min)	Starting Speed (mph)	Starting Grade (%)
<40	6.2	2.67
40-50	6.2	5.25
55-75	7.8	5.25

Grade Increase % (after every 3 minutes)

2.67
↓
5.25
↓
8.00
↓
10.50
↓
13.25

Analysis of Data

The analysis of data included the computation of the means and standard deviations of the measured and predicted maximal oxygen intake. All computations were done with the value expressed both in L/min and ml/kg·min.

The Pearson product moment correlation coefficient and the SEE were computed for each pair of predicted and measured values of VO2max (Appendix P).

Correlation Matrix

Test 1 = Astrand Treadmill Test
Test 2 = Maximal Combined Arm and Leg Test
Test 3 = Submaximal Combined Arm and Leg Test
Test 4 = Maximal Bicycle Test
Test 5 = Astrand-Rhyming Submaximal Bicycle Test

	Test 1	Test 2	Test 3	Test 4	Test 5
Test 1					
Test 2					
Test 3					
Test 4					
Test 5					

A multiple regression equation was designed for the submaximal combined arm and leg test for predicting values of maximal oxygen consumption. The criterion variable being VO2max measured from the treadmill test. The predictor variables were submaximal heart rate, oxygen consumption, and workload.

Reliability

A pilot study was performed one week prior to testing. Subjects performed each testing protocol twice. A total of five subjects for each test were involved in the pilot study. At least 24 hours time took place between Trial 1 and Trial 2 of each test.

Reliability of the maximal tests was based on the correlation between trial one and trial two's V02max of each mode. Reliability of the submaximal tests was based on the predictive value of V02max between trial one and trial two of the two modes. Mean difference was calculated between the two trials of each test.

Chapter 4

RESULTS

Reliability

The Pearson product-moment correlation coefficient formula, (Appendix P) was used to determine test-retest reliability of all maximal and the Astrand-Rhyming submaximal test procedures. Based on the test-retest results of five subjects, the results are presented in Table 8 and the trials are found in Appendix Q. There were no reliability coefficients below 0.65. The test-retest reliability coefficients ranged from 0.99 to 0.65. The absolute mean difference also appears in Appendix Q.

Table 8

Test-Retest Reliability

TESTING MODE	RELIABILITY COEFFICIENT		
	L/min	ml/kg·min	HR(bpm)
TREADMILL (max)	0.99	0.97	
BICYCLE (max)	0.96	0.98	
COMBINED (max)	0.95	0.91	
ASTRAND-RHYMING (submax)	0.99	0.95	0.65
COMBINED (submax)			0.80

Reliability for the submaximal combined arm and leg test involved correlation between subject's trial 1 heart rate and the subject's trial 2 HR for the same workload. The r value was 0.80.

The r value using the HR values for the Astrand-Rhuming test was 0.65. The test-retest data for the combined and Astrand-Rhyming test is found in Appendix R.

Predicted and Measured Maximal Dxygen Intake

There were 14 test results used for correlation purposes in this study. The tests were as follows: 1-2 Astrand Maximal Treadmill Test (L/min and ml/kg·min); 3-4 Maximal Combined Arm and Leg Test (L/min and ml/kg·min); 5-6 Maximal Bicycle Test (L/min and ml/kg·min); 7-8 Submaximal Combined Arm and Leg Test (L/min and ml/kg·min); 9-10 Astrand-Rhyming test with the age correction added (L/min and ml/kg·min); 11-12 Astrand-Rhyming test with no age correction added (L/min and ml/kg·min); 13-14 Predicted values using regression equation from submaximal bicycle results (L/min and ml/kg·min). Themeasured and predicted values for maximal oxygen consumption in L/min is presented in Table 10, the values in ml/kg·min are presented in Table 11.

The mean (given first) and the S.D. (given second) for V02max and the HR max are given for each parameter in Table 9.

Correlation Matrix

A correlation matrix was run with all 14 parameters for the intercorrelation of the data, (see Table 12). Within the correlation matrix, r's equal to or greater than a critical value of 0.46 were significant ($p < 0.01$). The degrees of freedom for the critical value of the correlation coefficient were n-2, which equaled 28.

Table 9

Mean Values of V02max and HRmax for each Parameter

	V02max		HRmax
	L/min	ml/kg·min	bpm
MEASURED VALUES			
TREADMILL	2.89 (.44)*	46.82 (4.96)	189 (7)
MAX COMBINED	2.61 (.41)	41.64 (4.98)	185 (7)
MAX BICYCLE	2.30 (.32)	37.15 (5.22)	177(10)
PREDICTED VALUES			
A-R with a.c.	2.51 (.81)	40.17(10.29)	
A-R	2.46 (.81)	39.74(10.40)	
SUB COMBINED	2.88 (.31)	47.15 (6.49)	
SUB BICYCLE	2.88 (.32)	46.99 (6.24)	

A-R = Astrand-Rhyming Test *value in parentheses is s.d.
a.c.= With age correction added

The Maximal Treadmill Test

The most significant correlation with the treadmill V02max value in L/min were the maximal combined test (0.77) and the maximal bicycle test (0.76). The value of treadmill V02max in ml/kg·min correlated highest with the maximal combined test (0.83) followed by the maximal bicycle test (0.78). All other parameters computed, significantly correlated with the maximal treadmill test in this order: for L/min: submaximal combined (0.73), submaximal bicycle and the Astrand-Rhyming prediction with the age correction (0.71), and the Astrand-Rhyming without an age correction (0.70); for ml/kg·min: submaximal combined (0.67), submaximal bicycle (0.57) and the Astrand-Rhyming test without age correction (0.47) and with age correction (0.46).

Table 10

Predicted and Measured Maximal Oxygen Intakes (L/min)

Subject Number	Measured Maximal Oxygen Intake			Predicted Maximal Oxygen Intake			
	TR	BIC	COM	AST-A	AST	BIC	COM
1	2.89	2.38	2.66	2.53	2.50	2.88	3.03
2	2.52	2.23	2.10	1.89	1.80	2.64	2.82
3	2.95	2.52	2.71	2.53	2.50	2.94	3.13
4	3.68	2.91	3.32	3.67	3.60	3.47	3.13
5	2.72	2.50	2.31	2.60	2.50	2.88	2.63
6	3.20	2.50	2.82	2.65	2.60	2.99	3.10
7	2.66	1.73	2.41	2.14	2.00	2.68	2.52
8	3.56	2.62	3.30	4.65	4.60	3.50	3.28
9	3.05	2.40	2.53	2.18	2.10	2.75	2.97
10	2.71	1.99	2.82	1.87	1.80	2.60	2.24
11	2.35	1.79	2.92	1.91	1.80	2.62	2.66
12	2.34	1.73	1.88	1.90	2.00	2.73	2.65
13	3.78	2.95	3.36	2.83	2.80	3.08	3.22
14	2.85	2.61	2.86	2.91	2.80	3.05	3.19
15	2.87	2.34	2.56	1.82	1.70	2.55	2.74
16	2.43	1.88	2.18	1.75	1.70	2.56	2.62
17	2.11	1.86	1.97	2.11	2.20	2.77	2.52
18	2.76	2.19	2.53	1.41	1.40	2.43	2.38
19	2.83	2.35	2.63	2.55	2.60	2.99	3.00
20	2.92	2.13	2.38	3.67	3.60	3.47	3.04
21	3.81	2.54	3.17	2.91	3.00	3.11	3.28
22	3.03	2.23	2.65	2.68	2.60	2.99	3.19
23	3.10	2.46	2.69	2.68	2.60	2.99	3.07
24	3.55	2.49	3.12	4.75	4.70	3.52	3.25
25	2.93	2.41	2.40	2.29	2.20	2.77	3.00
26	2.23	1.99	1.77	1.57	1.60	2.51	2.59
27	2.76	2.50	2.80	2.78	2.70	3.03	3.16
28	2.74	2.20	2.39	1.66	1.60	2.53	2.71
29	2.61	2.08	2.46	1.82	1.80	2.40	2.37
30	2.73	2.33	2.61	2.45	2.59	2.97	3.00
MEAN	2.89	2.30	2.61	2.51	2.46	2.88	2.88
S.D.	0.44	0.32	0.41	0.81	0.81	0.32	0.31

AST-A = Astrand-Rhyming Test with age correction TR=Treadmill
BIC = Bicycle COM=Combined

Table 11

Predicted and Measured Maximal Oxygen Intakes in ml/kg·min

Subject Number	Measured Maximal Oxygen Intake			Predicted Maximal Oxygen Intake			
	TR	BIC	COM	AST-A	AST	BIC	COM
1	58.71	48.56	54.36	51.80	51.17	58.96	62.00
2	47.06	41.72	39.24	35.36	33.67	49.39	52.70
3	44.27	37.86	40.31	38.02	37.57	44.22	47.00
4	45.74	36.27	42.36	45.62	44.75	43.09	38.90
5	41.24	38.36	35.00	39.49	38.00	43.74	39.98
6	48.99	38.57	43.38	40.55	39.80	45.71	47.40
7	39.82	25.64	35.63	31.94	29.90	39.94	37.67
8	45.44	32.30	40.10	57.02	56.41	42.98	40.28
9	47.54	37.34	39.38	34.02	32.71	42.79	46.31
10	40.05	28.60	41.36	27.61	26.55	38.29	33.08
11	44.06	33.28	35.82	35.73	33.70	49.03	49.88
12	44.17	32.90	35.46	35.92	37.80	51.51	50.06
13	55.08	42.90	48.53	41.26	40.85	44.87	47.00
14	50.01	45.46	50.01	50.91	48.95	53.39	55.80
15	52.07	43.07	46.18	33.04	30.88	46.35	49.81
16	40.33	31.23	36.25	29.06	28.21	42.53	43.44
17	41.52	36.64	38.65	41.49	43.22	54.41	49.50
18	47.09	37.88	43.59	24.49	24.24	42.07	41.27
19	47.68	39.98	44.52	42.86	43.73	50.25	50.53
20	57.91	42.35	46.88	72.86	71.42	68.88	60.22
21	54.31	36.41	45.13	41.42	42.70	44.26	46.70
22	43.94	32.30	38.62	38.73	37.60	43.20	46.13
23	47.65	37.82	41.38	41.20	40.00	45.96	47.18
24	43.33	30.30	38.10	57.89	57.30	42.88	39.68
25	45.62	37.54	37.38	35.58	34.20	43.07	46.72
26	42.17	30.90	33.46	29.70	30.30	47.98	48.97
27	48.01	43.46	48.01	48.45	47.04	52.79	55.05
28	50.07	40.07	44.18	30.79	29.60	46.80	50.15
29	45.09	35.88	42.59	31.43	31.11	41.42	40.92
30	45.48	38.76	43.52	40.83	41.67	39.42	50.07
MEAN	46.82	37.15	41.64	40.17	39.74	46.99	47.15
S.D.	04.96	05.22	04.98	10.29	10.40	06.24	06.49

Table 12

Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Max Treadmill (L/min)	1.00													
2. Max Treadmill (ml/kg·min)	-	1.00												
3. Max Combined (L/min)	0.77	-	1.00											
4. Max Combined (ml/kg·min)	-	0.83	-	1.00										
5. Max Bicycle (L/min)	0.76	-	0.70	-	1.00									
6. Max Bicycle (ml/kg·min)	-	0.78	-	0.79	-	1.00								
7. Sub Combined (L/min)	0.73	-	0.61	-	0.75	-	1.00							
8. Sub Combined (ml/kg·min)	-	0.67	-	0.53	-	0.75	-	1.00						
9. A-R with a.c. (L/min)	0.71	-	-	-	-	-	-	-	1.00					
10. A-R with a.c. (ml/kg·min)	-	0.46	-	-	-	-	-	-	-	1.00				
11. A-R (L/min)	0.70	-	0.63	-	0.33	-	0.36	-	-	-	1.00			
12. A-R (ml/kg·min)	-	0.47	-	0.42	-	0.30	-	0.42	-	-	-	1.00		
13. Sub Bicycle (L/min)	0.71	-	0.61	-	0.58	-	0.71	-	-	-	0.96	-	1.00	
14. Sub Bicycle (ml/kg·min)	-	0.57	-	0.45	-	0.59	-	0.97	-	-	-	0.64	-	1.00

r's equal to or greater than a critical value of 0.46 were significant ($p < 0.01$)

(-) = not computed

The Maximal Combined Arm and Leg Test

The most significant correlation with the maximal combined test in L/min was the maximal treadmill (0.77) followed by the maximal bicycle test (0.70). The submaximal tests computed were all significantly correlated to the maximal combined test. The most significant of those was the Astrand-Rhyming (0.63), followed by the submaximal combined and submaximal bicycle (0.61).

The values in ml/kg·min showed the treadmill correlating highest with the maximal combined test (0.83). The maximal bicycle next correlated highest with the maximal combined (0.79), followed by the submaximal combined (0.53), submaximal bicycle (0.45). The Astrand-Rhyming test was not significantly correlated.

The Maximal Bicycle Test

Maximal Treadmill (L/min) value significantly correlated with the maximal bicycle value (0.76). The submaximal combined test had the second highest correlating value of (0.75). Other significant correlations were the maximal combined (0.70) and the submaximal bicycle (0.58).

The most significant correlation with the maximal bicycle test in ml/kg·min was the maximal combined (0.79) followed by the treadmill (0.78), the submaximal combined (0.75), and the submaximal bicycle (0.59). The Astrand-Rhyming without age correction did not significantly correlate.

The Astrand-Rhyming Test

The predicted values of the Astrand-Rhyming were treated with the age correction and without the factor to see differences in the correlations with the treadmill test. The correlation values were almost identical with and without the age correction factor. The correlation with the age correction in L/min was 0.71 and in ml/kg·min was 0.46.

The Astrand-Rhyming test without the factor correlated best in L/min with the submaximal bicycle value (0.96). The maximal treadmill (0.70) and the maximal combined (0.63) significantly correlated with the Astrand-Rhyming test in L/min. Only two parameters significantly correlated with the Astrand-Rhyming when values were presented in ml/kg·min. They were the submaximal bicycle (0.64) and the treadmill (0.47).

The Submaximal Bicycle Test

The values of the results from the Astrand-Rhyming submaximal bicycle test were analyzed by multiple regression equation. The dependent variable being the maximal treadmill test value of VO2max and the independent variables being the submaximal heart rates and workloads of the submaximal bicycle test. The most significant correlation with the submaximal bicycle test was the Astrand-Rhyming test (0.96) in L/min and the submaximal combined (0.97) when the values are expressed in ml/kg·min. The other parameters which correlated with the submaximal bicycle test in L/min were:

treadmill (0.71), the submaximal combined (0.71), the maximal combined (0.61), and the maximal bicycle (0.58). Three remaining variables were significantly correlated with the submaximal bicycle test in ml/kg·min. The most significant of those was the Astrand-Rhyming test (0.64), the maximal bicycle (0.59), and the treadmill (0.57).

The Submaximal Combined Arm and Leg Test

A multiple regression equation was computed to predict V02max from the submaximal combined test. The V02max values of the maximal treadmill test was the dependent variable. The submaximal heart rate and workload were the independent variables. With the values expressed in L/min, the submaximal combined test most significantly correlated with the maximal bicycle test (0.75). Others which significantly correlated were the treadmill (0.73), the submaximal bicycle (0.71), and the maximal combined (0.61). The most significant correlation with the submaximal combined expressed in ml/kg·min was the submaximal bicycle (0.97), followed by the maximal bicycle (0.75) and the maximal treadmill (0.67), and the maximal combined (0.53).

Standard Errors of Estimate

The SEE for the predicted maximal oxygen intake with treadmill were: a) 0.212 L/min and 4.82 ml/kg·min for values using the submaximal combined arm and leg test; b) 0.226 L/min and 5.12 ml/kg·min for values using the submaximal bicycle test; c) 0.579 L/min and 9.16 ml/kg·min for the Astrand-Rhyming predictions; and

d) 0.572 L/min and 9.10 ml/kg·min for use of values using the Astrand-Rhyming test with age correction. The SEE for the predicted V02max and maximal combined test were: a) 0.246 L/min and 5.52 ml/kg·min for values of the submaximal combined; b) 0.253 L/min and 5.58 ml/kg·min for values using the submaximal bicycle predictions; c) 0.643 L/min and 9.45 ml/kg·min for values using the Astrand-Rhyming test. The SEE for the predicted V02max and the maximal bicycle test were: a) 0.208 L/min and 4.33 ml/kg·min for values using the submaximal combined predicted values; b) 0.261 L/min and 5.02 ml/kg·min for values of the submaximal test; and c) 0.72 L/min and 9.92 ml/kg·min for values using the Astrand-Rhyming test. A summary of the previous data is listed in Table 13.

Table 13

Standard Errors of Estimate

MODE	TREADMILL		MAX BICYCLE		MAX COMBINED	
	L/min	ml/kg·min	L/min	ml/kg·min	L/min	ml/kg·min
A-R with a.c.	.572	9.10	NC	NC	NC	NC
A-R	.579	9.16	.720	9.92	.630	9.45
Submaximal Bicycle	.226	5.12	.261	5.02	.253	5.58
Submaximal Combined	.212	4.82	.208	4.33	.246	5.52

NC = not computed

Multiple Regression Equations

Multiple regression analyses (see Table 14) were run to predict a y value. The dependent variable was V02max in L/min. The independent variable used for the prediction of the y value was derived from the heart rate and workload values of the submaximal combined test for equation 1. The heart rate and workload from the submaximal bicycle test were used for equation 2. The ml/kg·min value was then calculated from the predicted (L/min) value.

Table 14

Multiple Regression Equations

Dependent Variable	Equation	Independent Variables	T	R	R^2
SUBMAXIMAL COMBINED V02max (L/min)	Y = .0019 (1) - .0156 (2) + 4.36	1. WL 2. HR	4.92 -2.39	.73	.53
SUBMAXIMAL BICYCLE V02max (L/min)	Y = .0016 (3) - .011 (4) + 3.67	3. WL 4. HR	4.50 -1.55	.72	.52

Chapter 5

DISCUSSION

Introduction

The purpose of this study was to correlate the Astrand-Rhyming submaximal bicycle test and a submaximal combined arm and leg test to predict V02max. This study was also intended to determine the predictive accuracy of a submaximal test with the maximal value of a test using the same testing mode.

Thirty female subjects between the ages of 18 and 31 years performed a maximal stress test on the treadmill, one on the bicycle, and one on a combined arm and leg ergometer. The subjects also performed two submaximal tests, one on the bicycle and one on the combined arm and leg mode. The means and standard deviations were computed for the predictive values and measured values of V02max. All values were expressed in both L/min and ml/kg·min. A multiple regression equation was computed for the submaximal tests for predictive purposes. The dependent variable was V02max in L/min and the independent variables were the submaximal heart rate and workload. Maximal oxygen intake in ml/kg·min was then computed from the L/min data. The accuracy of the predictions were compared using correlation coefficients and the standard error of estimate.

Reliability

The test-retest reliability of the maximal tests ranged from 0.91 to 0.99. The Astrand-Rhyming submaximal procedure reliability coefficient ranged from 0.99 for L/min to 0.95 in ml/kg·min and 0.65 when HR used.

Williams (100) found at test-retest correlation coefficient of 0.64 for a single trial of the Astrand-Rhyming test. Williams (100) reports Day found the reliability of predicting from the nomogram to be 0.80 and that Dahlstron found it to be 0.83. The reliability of this study was above all values previously reported in the literature.

Numerous factors may affect the heart rate response to a submaximal exercise bout, thus reducing the reliability. Such factors include emotional state (12, 87), day to day variation in HR response, and the introduction of a new activity such as the combined arm and leg set up. The habituation period was used in this study to increase reliability values.

Maximal Oxygen Intake

The mean value for VO2max in ml/kg·min in this study for the treadmill test was 46.82 (4.96) with a range of 39.82 - 58.71 ml/kg·min. The mean value for VO2max in L/min from the treadmill was 2.89 + .44 with a range of 2.11 - 3.81. Drinkwater (34) found a value of 43.1 ml/kg·min in active women (ages 20-29) from her research, when using the treadmill, which was lower than the mean value found in this study. This may be due to different fitness levels.

The mean V02max value for the maximal bicycle test was 37.15 (5.22) in ml/kg·min and 2.30 (.32 in L/min. Vander et al. (93) using ten females (x = 29.8 years) found a mean V02max to be 2.02 L/min which was lower than the value in this study. Siconolfi (83) found a maximal value of 1.48 ± 0.41 L/min using the maximal bicycle test on 28 females ranging in age from 20-70 years. Differences were due to age and fitness level.

The mean value of maximal oxygen consumption for the combined arm and leg test was 2.61 (.41) L/min and 41.64 (4.98) ml/kg·min. Secher (81) found a value of 3.4 L/min in seven males. Gleser (42) found a mean value of 3.11 L/min for V02max in ten males using a combined arm and leg set up. The treadmill mode, overall attained the highest V02max which is in agreement with Hagan (43) who stated the cause was, "presumably due to the fact that the body weight must be lifted during this form of work, whereas during ergometer work the body is supported".

Correlation Coefficients

The Astrand-Rhyming Bicycle Test

The Astrand-Rhyming bicycle ergometer test in this study, significantly correlated with the V02max value from the treadmill, values range from 0.71 in L/min to 0.46 in ml/kg·min. These results are in agreement with results of Astrand (7) who found a correlative value of .63 for females. DeVries and Klafs (29) using the submaximal bicycle test found a .736 correlation between predicted and measured values. Tersalinna and Ismail (90) using the Astrand-Rhyming nomogram reported a .69 correlation between measured and predicted maximal oxygen intake.

The Submaximal Arm and Leg Test

The predicted value of V02max for the submaximal combined test significantly correlated with the V02max of the treadmill, ranging in value from 0.67 - 0.73. It also significantly correlated with the maximal bicycle (0.75) and the maximal combined test (0.53 for ml/kg·min and 0.61 for L/min). It appears the submaximal test correlated higher with the bicycle mode than it did with the combined or treadmill mode. No literature was found which used the submaximal arm and leg test as a predictor of V02max.

Multiple Regression Equations

The Submaximal Bicycle Test

A multiple regression equation was calculated in this study from the submaximal bicycle data. The equation was Y = .0016 (workload) - .011 (heart rate) + 3.67. The dependent variable being the maximal oxygen consumption value of the treadmill. The Astrand-Rhyming nomogram was based on values of a maximal bicycle test. The independent variables were the workload and heart rate of the submaximal bicycle test. The mean difference between the predictive values using this equation and the values from the Astrand-Rhyming nomogram were .560 for L/min and 9.19 for ml/kg·min. The predictive values (V02max) of the regression equation being consistently higher than the Astrand-Rhyming values with or without the age correction factor.

The Submaximal Combined Test

The multiple regression equation used for predicting maximal oxygen consumption from the submaximal combined test was Y = .0019 (workload) - .0156 (heart rate) + 4.36. The values calculated from the equation, correlated higher to the actual VO2max values (treadmill) than did the values of the equation of the submaximal bicycle test, the values of the Astrand-Rhyming test with the age correction, or the values of the Astrand-Rhyming test without the age correction.

Standard Errors of Estimate

The SEE of the predictions made using the Astrand-Rhyming nomogram with the Astrand age correction factor was .572 L/min and 9.10 ml/kg·min when using the maximal treadmill values. DeVries and Klafs (29) reported a SEE of .359 L/min for predictions using the Astrand-Rhyming nomogram. Davies (26) found a SEE of .843 L/min for predictions based on HR response between 120 and 140 bpm and .624 L/min using HR between 140 and 180 bpm. Astrand (8) stated, "The standard error of the method for the prediction of maximal oxygen uptake from submaximal exercise tests is about 10% in relatively well-trained individuals of the same age, but up to 15% on moderately trained individuals of different ages when the correction of maximal oxygen uptake is applied". The SEE using the regression equation for the submaximal bicycle test was lower than the values reported in the literature. The SEE for the combined arm and leg predictive values was .212 L/min and 4.82 ml/kg·min, which was lower than the SEE of the other submaximal tests.

Summary of Predictive Values

The submaximal arm and leg test had a higher correlative value and lower SEE when compared to the use of the Astrand-Rhyming test with or without the age correction factor added. The values of the submaximal tests correlated higher when expressed in L/min than in ml/kg·min. Therefore, the predicted maximal oxygen consumption should be predicted from the L/min values.

The correlation between homogeneous testing showed that the mode did not play an important part in this study. The submaximal combined arm and leg test correlated higher with the maximal bicycle and treadmill than it did with the maximal combined mode. The submaximal bicycle correlated higher with the maximal combined and treadmill when values were expressed in L/min. When the values were expressed in ml/kg·min, the bicycle test correlated highest with the same bicycle mode.

The values of the Astrand-Rhyming predictions were more accurate when the age correction was not used. These results may be due to the small variation between subjects' ages. Astrand (90) reported a correlation coefficient of .709 without the age correction and a .92 correlation with the factor added. Glassford et al. (41) claimed that in their study, the correction factor was used for the values to obtain the correction coefficient of .80.

The use of the combined arm and leg test may be useful in the clinical setting because it utilizes greater muscle mass than does the bicycle test alone. Bergh (17) reported that, "V02max is dependent on the exercising muscle mass. However, this does not necessarily mean that this exercise muscle mass sets the upper limit for maximal aerobic capacity". The mean value of V02max from the combined exercise was less than the treadmill value, but greater than the bicycle mode, which is in agreement with the literature. Gleser (42) found a 10% increase in V02 by adding arm work to maximal leg work in ten males.

The submaximal values of V02 for combined exercise were consistently higher than the submaximal bicycle mode at any given workload. This agrees with Gleser (42). The same results applied to V02 when plotted against HR. Reybrouck (74) on the other hand stated, "For a given work rate at submaximal levels, we found no difference for V02 for arm, leg or combined arm-leg ergometry".

The mean value of maximal heart rate for the treadmill was 189 (7.57) bpm, for the combined exercise was 185 (7.50); and for the maximal bicycle was 177 (10.63). These results agree with the results of Bergh (17) who found the highest heart rate attained with the treadmill when compared to the combined arm-leg, and the bicycle mode. Seals and Mullin (80) found the combined arm and leg mode elicited a higher maximal heart rate than did the bicycle ergometer.

Predicting V02max is limited by the fact that predicting maximal HR is difficult and varies within any given age group or fitness category. At any given level of submaximal work. the pulse rate can vary independently of the oxygen uptake, but directly with emotional state. Therefore, submaximal testing predictions can only be as accurate as the prediction of maximal heart rate. When limited to the use of submaximal testing, the combined arm and leg test is a possible method of choice in predicting treadmill VO2max with accuracy.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study evaluated the predictive accuracy of a submaximal combined arm and leg test. The study was conducted at the University of Kansas using 30 college-aged females as subjects ($\bar{x}$ age = 23.00 years). The Astrand maximal treadmill test was the means by which V02max was determined for each subject. The subjects also performed a maximal test on the bicycle ergometer and one on a combined arm and leg ergometer, and submaximal tests using the Astrand-Rhyming protocol on the bicycle and a submaximal combined arm and leg protocol. The maximal oxygen intake was predicted from heart rate response to the submaximal workload using the Astrand-Rhyming nomogram with the bicycle mode. The predictive value of the combined arm and leg test was computed from a multiple regression equation.

The mean and standard deviation of the measured maximal oxygen intake was 2.89 (.44) L/min and 46.82 (4.96) ml/kg·min for the treadmill; 2.61 (.41) L/min and 41.64 (4.98) ml/kg·min for the combined mode; and 2.30 (.32) L/min and 37.15 (5.22) ml/kg·min for the bicycle. The mean predicted value using the Astrand-Rhyming nomogram and age correction factor was 2.51 (.81) L/min and 40.17 (10.29) ml/kg·min, and using the submaximal combined equation was 2.88 (.31) L/min and 47.15 (6.49) ml/kg·min.

The correlation coefficients between the predicted values and the measured value (treadmill) were .73 for L/min and .67 ml/kg·min when using the combined mode, and .71 for L/min and .46 ml/kg·min when using the Astrand-Rhyming prediction, corrected for age.

The submaximal combined test correlated higher with the maximal bicycle (.75) and the treadmill (.67) than it did with the maximal combined (.53). The submaximal bicycle test correlated higher with the maximal bicycle (.59) when expressed in ml/kg.min, when expressed in L/min, the maximal treadmill and the submaximal bicycle correlated best (.71).

The multiple regression equation for the submaximal combined arm-leg protocol was: $Y = .0019\ (\text{workload}) - .0156\ (\text{HR}) + 4.36$ and a multiple regression was computed from the submaximal bicycle data: $Y = .0016\ (\text{workload}) - .011\ (\text{HR}) + 3.67$.

Conclusions

Within the scope and limitations of this study, the following conclusions have been drawn on the basis of the results:

1. For female subjects between the ages of 18 and 31, the maximal oxygen intake elicited by the Astrand treadmill test gives the highest value when compared to a maximal bicycle test or combined arm and leg test.

2. The maximal combined arm and leg test elicits a higher V02max value than does the maximal bicycle.

3. When predicting maximal oxygen consumption, from submaximal test modes, the combined arm-leg test correlates better with the measured value of V02max than does the submaximal bicycle test for treadmill values.

4. From this study, the submaximal combined arm-leg test correlated best with the maximal bicycle test and not with the maximal combined mode.

5. The submaximal bicycle test correlated higher with the maximal treadmill test than it did with the maximal bicycle test.

6. The submaximal combined arm-leg test is the method of choice in predicting treadmill maximal oxygen consumption.

7. Submaximal predictions are not mode specific.

8. The prediction of maximal oxygen consumption from submaximal testing provides only a rough estimate of the actual value; for accurate analysis of the aerobic work capacity, direct measurement is necessary.

Recommendations

This study did not encompass many parameters, the following recommendations are for future studies:

1. College females with a wider range of conditioning levels should be investigated.

2. Females with a wider age range should be investigated.

3. Groups made up of subjects of a different sex or ethnic group should be tested. This could possibly add further validity to the results found in this investigation.

4. A nomogram should be developed using the regression equation for the combined arm-leg exercise for predicting V02max.

5. Procedural differences including increasing rpm to increase submaximal HR.

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APPENDIX A

Table 15 (28:262)

Norms for Maximal O_2 Consumption (Aerobic Working Capacity)

Women

Age	Low	Fair	Average	Good	High
20-29	1.69	1.70-1.99	2.00-2.49	2.50-2.79	2.80 +
	28	29-34	35-43	44-48	49 +
30-39	1.59	1.60-1.89	1.90-2.39	2.40-2.69	2.70 +
	27	28-33	34-41	42-47	48 +
40-49	1.49	1.50-1.79	1.80-2.29	2.30-2.59	2.60 +
	25	26-31	32-40	41-45	46 +
50-65	1.29	1.30-1.59	1.60-2.09	2.10-2.39	2.40 +
	21	22-28	29-36	37-41	42 +

Men

Age	Low	Fair	Average	Good	High
20-29	2.79	2.80-3.09	3.10-3.69	3.70-3.99	4.00 +
	38	39-43	44-51	52-56	57 +
30-39	2.49	2.50-2.79	2.80-3.39	3.40-3.69	3.70 +
	34	35-39	40-47	48-51	52 +
40-49	2.19	2.20-2.49	2.50-3.09	3.10-3.39	3.40 +
	30	31-35	36-43	44-47	48 +
50-59	1.89	1.90-2.19	2.20-2.79	2.80-3.09	3.10 +
	25	26-31	32-39	40-43	44 +
60-69	1.59	1.60-1.89	1.90-2.49	2.50-2.79	2.80 +
	21	22-26	27-35	36-39	40 +

Lower figure = milliliters of O_2 per kilogram body weight.

From I. Astrand, *Acta Physiol. Scand.* 49 (suppl.169), 1960.

APPENDIX B

AGE CORRECTION FACTORS

for Astrand-Rhyming Bicycle Test

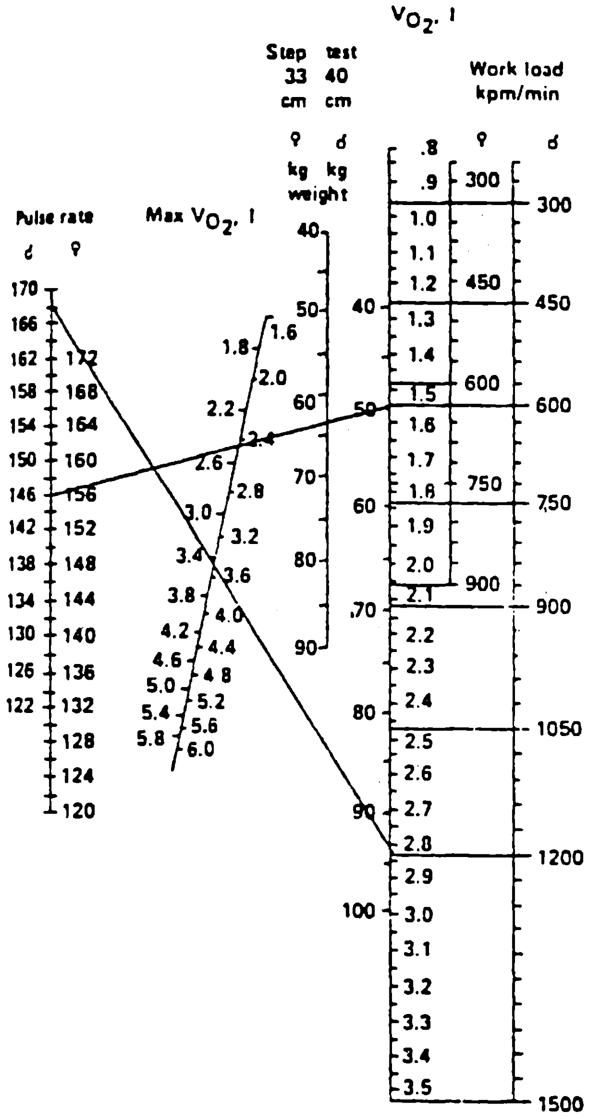
AGE

15 = 1.10
16 = 1.09
17 = 1.08
18 = 1.07
19 = 1.06
20 = 1.05
21 = 1.04
22 = 1.03
23 = 1.02
24 = 1.01
25 = 1.00
26 = 0.99
27 = 0.98
28 = 0.97
29 = 0.97
30 = 0.96
31 = 0.95
32 = 0.94
33 = 0.93
34 = 0.93
35 = 0.92
36 = 0.91
37 = 0.90
38 = 0.90
39 = 0.89
40 = 0.88
41 = 0.87
42 = 0.86
43 = 0.85
44 = 0.84
45 = 0.84
46 = 0.83
47 = 0.82
48 = 0.82
49 = 0.81
50 = 0.81
51 = 0.80
52 = 0.79
53 = 0.79
54 = 0.78
55 = 0.77
56 = 0.77
57 = 0.76
58 = 0.75
59 = 0.74
60 = 0.73
61 = 0.73
62 = 0.72
63 = 0.71
64 = 0.70
65 = 0.69
66 = 0.69
67 = 0.68

(94)VonDobelin,W. Astrand, I., and Bergstrom, A. An analysis of age and other factors related to maximal oxygen uptake. J. Appl. Physiol. 22 (5): 934-938, 1967.

APPENDIX C (28:259)

ASTRAND-RHYMING NOMOGRAM



APPENDIX D

Table 16

Prediction of Maximal Oxygen Intake from Heart Rate and Workload on a Bicycle Ergometer - Females (28:261)

Heart rate	Maxial Oxygen Uptake litres/min.					Heart rate	Maxial Oxygen Uptake litres/min.				
	300 kpm/min	450 kpm/min	600 kpm/min	750 kpm/min	900 kpm/min		300 kpm/min	450 kpm/min	600 kpm/min	750 kpm/min	900 kpm/min
120	2.6	3.4	4.1	4.8		148	1.6	2.1	2.6	3.1	3.6
121	2.5	3.3	4.0	4.8		149		2.1	2.6	3.0	3.5
122	2.5	3.2	3.9	4.7		150		2.0	2.5	3.0	3.5
123	2.4	3.1	3.9	4.6		151		2.0	2.5	3.0	3.4
124	2.4	3.1	3.8	4.5		152		2.0	2.5	2.9	3.4
125	2.3	3.0	3.7	4.4		153		2.0	2.4	2.9	3.3
126	2.3	3.0	3.6	4.3		154		2.0	2.4	2.8	3.3
127	2.2	2.9	3.5	4.2		155		1.9	2.4	2.8	3.2
128	2.2	2.8	3.5	4.2	4.8	156		1.9	2.3	2.8	3.2
129	2.2	2.8	3.4	4.1	4.8	157		1.9	2.3	2.7	3.2
130	2.1	2.7	3.4	4.0	4.7	158		1.8	2.3	2.7	3.1
131	2.1	2.7	3.4	4.0	4.6	159		1.8	2.2	2.7	3.1
132	2.0	2.7	3.3	3.9	4.5	160		1.8	2.2	2.6	3.0
133	2.0	2.6	3.2	3.8	4.4	161		1.8	2.2	2.6	3.0
134	2.0	2.6	3.2	3.8	4.4	162		1.8	2.2	2.6	3.0
135	2.0	2.6	3.1	3.7	4.3	163		1.7	2.2	2.6	2.9
136	1.9	2.5	3.1	3.6	4.2	164		1.7	2.1	2.5	2.9
137	1.9	2.5	3.0	3.6	4.2	165		1.7	2.1	2.5	2.9
138	1.8	2.4	3.0	3.5	4.1	166		1.7	2.1	2.5	2.8
139	1.8	2.4	2.9	3.5	4.0	167		1.6	2.1	2.4	2.8
140	1.8	2.4	2.8	3.4	4.0	168		1.6	2.0	2.4	2.8
141	1.8	2.3	2.8	3.4	3.9	169		1.6	2.0	2.4	2.8
142	1.7	2.3	2.8	3.3	3.9	170		1.6	2.0	2.4	2.7
143	1.7	2.2	2.7	3.3	3.8						
144	1.7	2.2	2.7	3.2	3.8						
145	1.6	2.2	2.7	3.2	3.7						
146	1.6	2.2	2.6	3.2	3.7						
147	1.6	2.1	2.6	3.1	3.6						

APPENDIX E

Table 17

Prediction of Maximal Oxygen Intake from Heart Rate and Workload on a Bicycle Ergometer -- Males (12:260)

Heart rate	Maxial Oxygen Uptake litres/min.				
	300 kpm/min	600 kpm/min	900 kpm/min	1200 kpm/min	1500 kpm/min
120	2.2	3.5	4.8		
121	2.2	3.4	4.7		
122	2.2	3.4	4.6		
123	2.1	3.4	4.6		
124	2.1	3.3	4.5	6.0	
125	2.0	3.2	4.4	5.9	
126	2.0	3.2	4.4	5.8	
127	2.0	3.1	4.3	5.7	
128	2.0	3.1	4.2	5.6	
129	1.9	3.0	4.2	5.6	
130	1.9	3.0	4.1	5.5	
131	1.9	2.9	4.0	5.4	
132	1.8	2.9	4.0	5.3	
133	1.8	2.8	3.9	5.3	
134	1.8	2.8	3.9	5.2	
135	1.7	2.8	3.8	5.1	
136	1.7	2.7	3.8	5.0	
137	1.7	2.7	3.7	5.0	
138	1.6	2.7	3.7	4.9	
139	1.6	2.6	3.6	4.8	
140	1.6	2.6	3.6	4.8	6.0
141		2.6	3.5	4.7	5.9
142		2.5	3.5	4.6	5.8
143		2.5	3.4	4.6	5.7
144		2.5	3.4	4.5	5.7
145		2.4	3.4	4.5	5.6
146		2.4	3.3	4.4	5.6
147		2.4	3.3	4.4	5.5
148		2.4	3.2	4.3	5.4
149		2.3	3.2	4.3	5.4
150		2.3	3.2	4.2	5.3
151		2.3	3.1	4.2	5.2
152		2.3	3.1	4.1	5.2
153		2.2	3.0	4.1	5.1
154		2.2	3.0	4.0	5.1
155		2.2	3.0	4.0	5.0
156		2.2	2.9	4.0	5.0
157		2.1	2.9	3.9	4.9
158		2.1	2.9	3.9	4.9
159		2.1	2.8	3.8	4.8
160		2.1	2.8	3.8	4.8
161		2.0	2.8	3.7	4.7
162		2.0	2.8	3.7	4.6
163		2.0	2.8	3.7	4.6
164		2.0	2.7	3.6	4.5
165		2.0	2.7	3.6	4.5
166		1.9	2.7	3.6	4.5
167		1.9	2.6	3.5	4.4
168		1.9	2.6	3.5	4.4
169		1.9	2.6	3.5	4.3
170		1.8	2.6	3.4	4.3

APPENDIX F

Table 18

Conversion of Maximal Oxygen Intake in L/min to ml/kg·min (8)

Body Weight		Maximum Oxygen Uptake - litres/min.																								
pound	kg	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
110	50	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78
112	51	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	76
115	52	29	31	33	35	37	38	40	42	44	46	48	50	52	54	56	58	60	62	63	65	67	69	71	73	75
117	53	28	30	32	34	36	38	40	42	43	45	47	49	51	53	55	57	58	60	62	64	66	68	70	72	74
119	54	28	30	31	33	35	37	39	41	43	44	46	48	50	52	54	56	57	59	61	63	65	67	69	70	72
121	55	27	29	31	33	35	36	38	40	42	44	45	47	49	51	53	55	56	58	60	62	64	65	67	69	71
123	56	27	29	30	32	34	36	38	39	41	43	45	46	48	50	52	54	55	57	59	61	63	64	66	68	70
126	57	26	28	30	32	33	35	37	39	40	42	44	46	47	49	51	53	54	56	58	60	61	63	65	67	68
128	58	26	28	29	31	33	34	36	38	40	41	43	45	47	48	50	52	53	55	57	59	60	62	64	66	67
130	59	25	27	29	31	32	34	36	37	39	41	42	44	46	47	49	51	53	54	56	58	59	61	63	64	66
132	60	25	27	28	30	32	33	35	37	38	40	42	43	45	47	48	50	52	53	55	57	58	60	62	63	65
134	61	25	26	28	30	31	33	34	36	38	39	41	43	44	46	48	49	51	52	54	56	57	59	61	62	64
137	62	24	26	27	29	31	32	34	35	37	39	40	42	44	45	47	48	50	52	53	55	56	58	60	61	63
139	63	24	25	27	29	30	32	33	35	37	38	40	41	43	44	46	48	49	51	52	54	56	57	59	60	62
141	64	23	25	27	28	30	31	33	34	36	38	39	41	42	44	45	47	48	50	52	53	55	56	58	59	61
143	65	23	25	26	28	29	31	32	34	35	37	38	40	42	43	45	46	48	49	51	52	54	55	57	58	60
146	66	23	24	26	27	29	30	32	33	35	36	38	39	41	42	44	45	47	48	50	52	53	55	56	58	59
148	67	22	24	25	27	28	30	31	33	34	36	37	39	40	42	43	45	46	48	49	51	52	54	55	57	58
150	68	22	24	25	26	28	29	31	32	34	35	37	38	40	41	43	44	46	47	49	50	51	53	54	56	57
152	69	22	23	25	26	28	29	30	32	33	35	36	38	39	41	42	43	45	46	48	49	51	52	54	55	57
154	70	21	23	24	26	27	29	30	31	33	34	36	37	39	40	41	43	44	46	47	49	50	51	53	54	56
157	71	21	23	24	25	27	28	30	31	32	34	35	37	38	39	41	42	44	45	46	48	49	51	52	54	55
159	72	21	22	24	25	26	28	29	31	32	33	35	36	38	39	40	42	43	44	46	47	49	50	51	53	54
161	73	21	22	23	25	26	27	29	30	32	33	34	36	37	38	40	41	42	44	45	47	48	49	51	52	53
163	74	20	22	23	24	26	27	28	30	31	32	34	35	36	38	39	41	42	43	45	46	47	49	50	51	53
165	75	20	21	23	24	25	27	28	29	31	32	33	35	36	37	39	40	41	43	44	45	47	48	49	51	52
168	76	20	21	22	24	25	26	28	29	30	32	33	34	36	37	38	39	41	42	43	45	46	47	49	50	51
170	77	19	21	22	23	25	26	27	29	30	31	32	34	35	36	38	39	40	42	43	44	45	47	48	49	51
172	78	19	21	22	23	24	26	27	28	29	31	32	33	35	36	37	38	40	41	42	44	45	46	47	49	50
174	79	19	20	22	23	24	25	27	28	29	30	32	33	34	35	37	38	39	41	42	43	44	46	47	48	49
176	80	19	20	21	23	24	25	26	28	29	30	31	33	34	35	36	38	39	40	41	43	44	45	46	48	49
179	81	19	20	21	22	23	25	26	27	28	30	31	32	33	35	36	37	38	40	41	42	43	44	46	47	48
181	82	18	20	21	22	23	24	26	27	28	29	30	32	33	34	35	37	38	39	40	41	43	44	45	46	48
183	83	18	19	20	22	23	24	25	27	28	29	30	31	33	34	35	36	37	39	40	41	42	43	45	46	47
185	84	18	19	20	21	23	24	25	26	27	29	30	31	32	33	35	36	37	38	39	40	42	43	44	45	46
187	85	18	19	20	21	22	24	25	26	27	28	29	31	32	33	34	35	36	38	39	40	41	42	44	45	46
190	86	17	19	20	21	22	23	24	26	27	28	29	30	31	33	34	35	36	37	38	40	41	42	43	44	45
192	87	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	34	36	37	38	39	40	41	43	44	45
194	88	17	18	19	20	22	23	24	25	26	27	28	30	31	32	33	34	35	36	38	39	40	41	42	43	44
196	89	17	18	19	20	21	22	24	25	26	27	28	29	30	31	33	34	35	36	37	38	39	40	42	43	44
198	90	17	18	19	20	21	22	23	24	26	27	28	29	30	31	32	33	34	36	37	38	39	40	41	42	43
201	91	16	18	19	20	21	22	23	24	25	26	27	29	30	31	32	33	34	35	36	37	38	40	41	42	43
203	92	16	17	18	20	21	22	23	24	25	26	27	28	29	30	32	33	34	35	36	37	38	39	40	41	42
205	93	16	17	18	19	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	37	38	39	40	41	42
207	94	16	17	18	19	20	21	22	23	24	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
209	95	16	17	18	19	20	21	22	23	24	25	26	27	28	29	31	32	33	34	35	36	37	38	39	40	41
212	96	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	38	39	40	41
214	97	15	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
216	98	15	16	17	18	19	20	21	22	23	24	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
218	99	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
220	100	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39

Table 18 (continued)

Body Weight		Maximum Oxygen Uptake - litres/min.																				
pound	kg	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
110	50	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
112	51	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118
115	52	77	79	81	83	85	87	88	90	92	94	96	98	100	102	104	106	108	110	112	113	115
117	53	75	77	79	81	83	85	87	89	91	92	94	96	98	100	102	104	106	108	109	111	113
119	54	74	76	78	80	81	83	85	87	89	91	93	94	96	98	100	102	104	106	107	109	111
121	55	73	75	76	78	80	82	84	85	87	89	91	93	95	96	98	100	102	104	105	107	109
123	56	71	73	75	77	79	80	82	84	86	88	89	91	93	95	96	98	100	102	104	105	107
126	57	70	72	74	75	77	79	81	82	84	86	88	89	91	93	95	96	98	100	102	104	105
128	58	69	71	72	74	76	78	79	81	83	84	86	88	90	91	93	95	97	98	100	102	103
130	59	68	69	71	73	75	76	78	80	81	83	85	86	88	90	92	93	95	97	98	100	102
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134	61	66	67	69	70	72	74	75	77	79	80	82	84	85	87	89	90	92	93	95	97	98
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139	63	63	65	67	68	70	71	73	75	76	78	79	81	83	84	86	87	89	90	92	94	95
141	64	63	64	66	67	69	70	72	73	75	77	78	80	81	83	84	86	88	89	91	92	94
143	65	62	63	65	66	68	69	71	72	74	75	77	78	80	82	83	85	86	88	89	91	92
146	66	61	62	64	65	67	68	70	71	73	74	76	77	79	80	82	83	85	86	88	89	91
148	67	60	61	63	64	66	67	69	70	72	73	75	76	78	79	81	82	84	85	87	88	90
150	68	59	60	62	63	65	66	68	69	71	72	74	75	76	78	79	81	82	84	85	87	88
152	69	58	59	61	62	64	65	67	68	70	71	72	74	75	77	78	80	81	83	84	86	87
154	70	57	59	60	61	63	64	66	67	69	70	71	73	74	76	77	79	80	81	83	84	86
157	71	56	58	59	61	62	63	65	66	68	69	70	72	73	75	76	77	79	80	82	83	85
159	72	56	57	58	60	61	63	64	65	67	68	69	71	72	74	75	76	78	79	81	82	83
161	73	55	56	58	59	60	62	63	64	66	67	68	70	71	73	74	75	77	78	79	81	82
163	74	54	55	57	58	59	61	62	64	65	66	68	69	70	72	73	74	76	77	78	80	81
165	75	53	55	56	57	59	60	61	63	64	65	67	68	69	71	72	73	75	76	77	79	80
168	76	53	54	55	57	58	59	61	62	63	64	66	67	68	70	71	72	74	75	76	78	79
170	77	52	53	55	56	57	58	60	61	62	64	65	66	68	69	70	71	73	74	75	77	78
172	78	51	53	54	55	56	58	59	60	62	63	64	65	67	68	69	71	72	73	74	76	77
174	79	51	52	53	54	56	57	58	59	61	62	63	65	66	67	68	70	71	72	73	75	76
176	80	50	51	53	54	55	56	58	59	60	61	63	64	65	66	68	69	70	71	72	74	75
179	81	49	51	52	53	54	56	57	58	59	60	62	63	64	65	67	68	69	70	72	73	74
181	82	49	50	51	52	54	55	56	57	59	60	61	62	63	65	66	67	68	70	71	72	73
183	83	48	49	51	52	53	54	55	57	58	59	60	61	63	64	65	66	67	69	70	71	72
185	84	48	49	50	51	52	54	55	56	57	58	60	61	62	63	64	65	67	68	69	70	71
187	85	47	48	49	51	52	53	54	55	56	58	59	60	61	62	64	65	66	67	68	69	71
190	86	47	48	49	50	51	52	53	55	56	57	58	59	60	62	63	64	65	66	67	69	70
192	87	46	47	48	49	51	52	53	54	55	56	57	59	60	61	62	63	64	66	67	68	69
194	88	45	47	48	49	50	51	52	53	55	56	57	58	59	60	61	63	64	65	66	67	68
196	89	45	46	47	48	49	51	52	53	54	55	56	57	58	60	61	62	63	64	65	66	67
198	90	44	46	47	48	49	50	51	52	53	54	56	57	58	59	60	61	62	63	64	66	67
201	91	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	60	62	63	64	65	66
203	92	43	45	46	47	48	49	50	51	52	53	54	55	57	58	59	60	61	62	63	64	65
205	93	43	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	60	61	62	63	64
207	94	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	59	60	61	62	63	64
209	95	42	43	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	60	61	62	63
212	96	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	63
214	97	41	42	43	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	60	61	62
216	98	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
218	99	40	41	42	43	44	45	46	47	48	49	51	52	53	54	55	56	57	58	59	60	61
220	100	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

APPENDIX G

PHYSICAL ACTIVITY QUESTIONNAIRE

Name: Age: Ht: Wgt:

Local Address: Home Phone:

1. Are you presently involved in any systematic type of conditioning program in which you exercise once per week or more? ____________

   What activity? ____

   How many times per week? ________________________________

   How long each time? ____________________________________

   Average mileage per week, if applicable? ________________

2. Do you smoke tobacco? ____________________ How much? ________

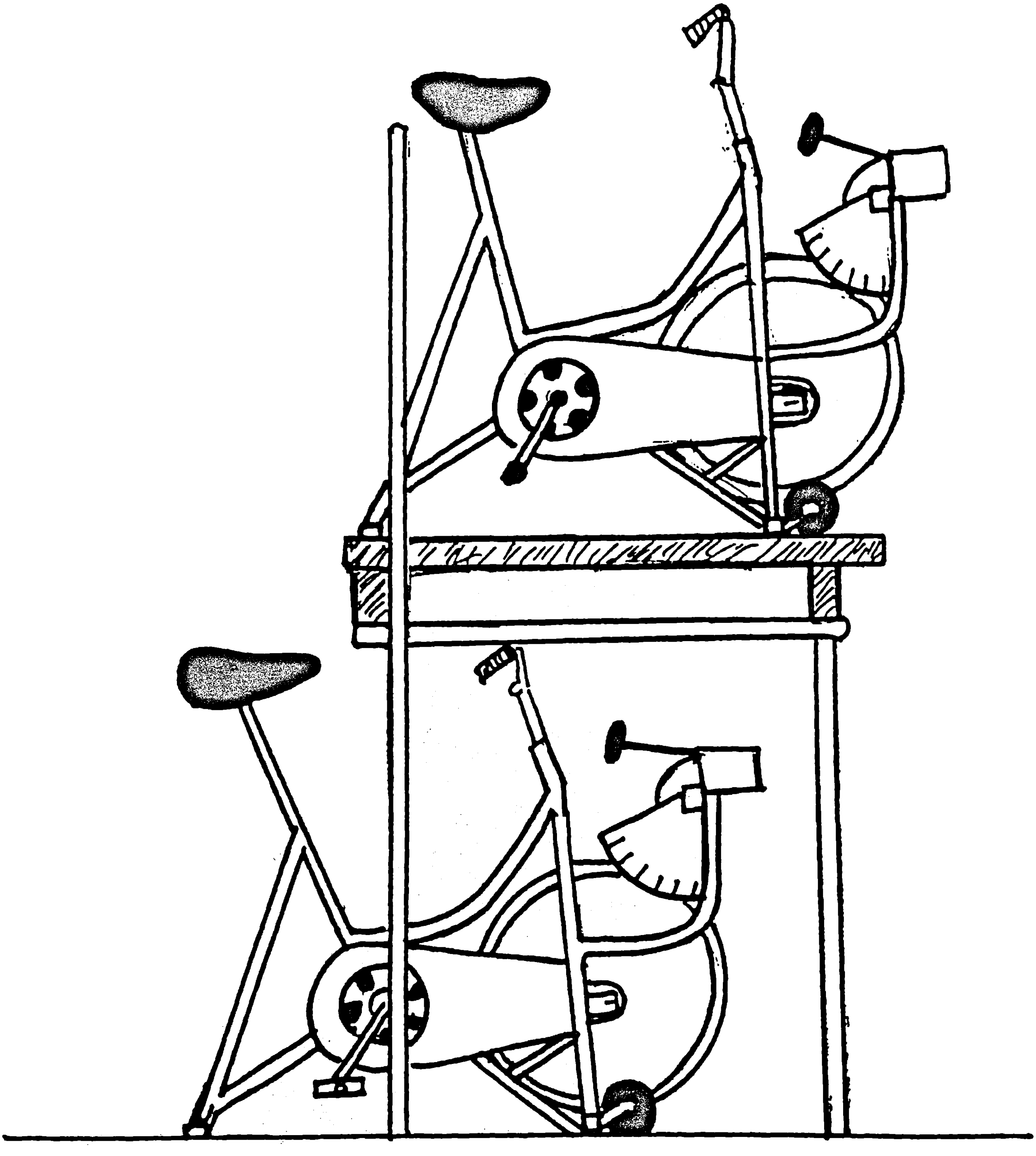
3. Do you or have you had: Diabetes ______________________

   High Blood Pressure ________________

   Long term illness __________________

   Heart problems ____________________

APPENDIX H



APPENDIX I

Instructions for Subjects

1. Be on time. If you are unable to keep your appointment, please call the Exercise Physiology Laboratory at 864-3385.
2. Do not eat anything during the two hours prior to the test.
3. Do not smoke, drink coffee, tea, coke, cocoa, or anything containing caffeine during the three hours prior to the test.
4. Avoid medications, drugs, etc., that might alter your heart rate or affect your test performance.
5. Do not perform any strenuous, exhausting exercise prior to the test.
6. Try to get a good night's rest prior to the test day.
7. Bring comfortable shorts, shoes, and socks to wear during the test.

APPENDIX J

Proposed Experimental Activities

Submaximal Stress Tests

Bicycle Ergometer Procedures:

The subject will perform an incremental workload on the bicycle ergometer. The resistance will be increased at apecified time intervals. Criteria for termination include a target heart rate, voluntary termination on the part of the subject, adverse changes in the electrocardiogram, or adverse changes in blood pressure if monitored.

Combined Arm and Leg Test:

The subject will be seated on a stationary bicycle. The subject will pedal the bicycle at a rate of 50 rpm at a single workload. Simultaneously the subject will crank another bicycle set at the subject's chest level. The workload will be approximately 20-25% the total workload. The test is terminated when the subject reaches a steady state heart rate between 130 and 170 beats per minute.

Purpose:

The steady state heart rate response to a single submaximal workload can be used to predict the subject's maximal oxygen intake. The submaximal test also serves as a warm-up period prior to the maximal oxygen intake test.

Discomfort and/or Risks:

Because the test does not require maximal effort, there is usually minimal risk associated with the procedure. Some subjects may experience discomfort of the thigh or calf or arm muscles.

Maximal Oxygen Intake Test

Treadmill Test:

This involves a supramaximal run on the treadmill while expired air is collected in meteorological balloons. The angle of incline is increased at the end of each three minutes until the subject is unable to continue. An ECG is always monitored. The test is preceded by a submaximal run as a warm-up period.

APPENDIX J (continued)

Bicycle Test:

This involves a supramaximal ride on a stationary bicycle while expired air is collected in meteorological balloons. An ECG is always monitored. The pedalling speed remains constant, but the workload is increased at the end of the second minute and every following minute. The test is begun with a pedalling speed of 60 rpm and a workload of 150 kpm/min.

Combined Arm and Leg Test:

This involves a supramaximal ride on a stationary bicycle with simultaneous arm work on a second bike set at the subject's chest level. Expired air is collected and an ECG is always monitored. The pedalling speed remains constant, but the workload is increased at the end of the second minute and every following minute. The test is begun with a pedalling speed of 60 rpm and a workload of 150 kpm/min.

Purpose:

Maximal oxygen intake is generally considered to be the single best measure of cardiorespiratory fitness. The purpose is to determine the maximum amount of oxygen that the subject's body can use per minute.

Discomfort and/or Risks:

The test is rather traumatic because it involves an all out performance. The legs usually become rubbery, the arms start to ache, breathing becomes labored, and the subject becomes unable to maintain the pedalling speed. The breathing apparatus makes it difficult to swallow so the mouth tends to become dry and the ears plug up. Due to its maximal nature, the test is only administered to subjects under 35 years of age.

APPENDIX K

Subject Informed Consent

Exercise Physiology Lab
Department of Health,
Physical Education, and
Recreation, The University
of Kansas

Date ______________19____

The Department of HPER supports the practice of protection for human subjects participating in research. Please read the accompanying procedure and "Instructions for Subjects". The testing procedures include two submaximal tests and three maximal oxygen intake tests. A brief orientation period will be held prior to the start of the testing. If you have any questions, please ask them.

Your participation in this project is voluntary and you may withdraw at any time. The expected benefits associated with your participation include information regarding your personel state of fitness and the satisfaction of helping to increase physiological knowledge.

The project will be under the direction of Janice Loudon, but other persons may be associated with the data collection. The obtained data may be used in reports or publications, but your identity will not be associated with such reports.

Please give your consent with full knowledge of the nature and purpose of the procedures, the benefits that you may expect, and the discomforts and/or risks that you may encounter. Compensation for physical injury that results from the research is not provided. We appreciate your assistance.

Sincerely,

Janice Loudon
Project Director
864-3385

Dr. Tom R. Thomas
Laboratory Director

____
Signature of Subject

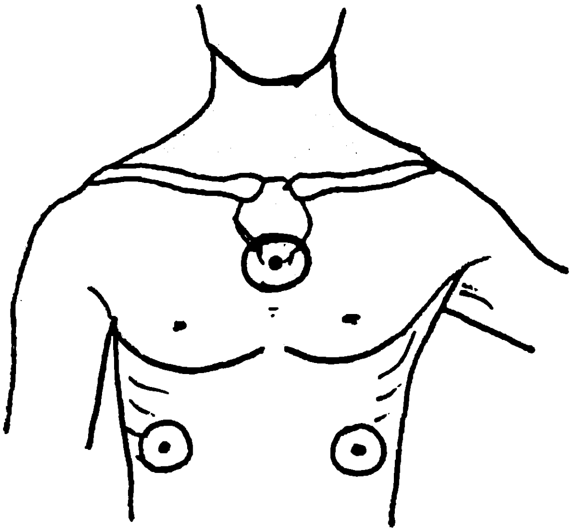
____

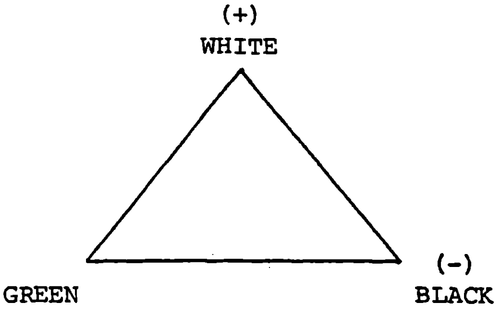
____
Address

____
Telephone Number

APPENDIX L

Lead II





APPENDIX M

RESTING DATA

Weight_______________lbs. ÷ 2.2 = ____________kg

Vital Capacity_______________Resting Blood Pressure___________Resting HR__________

Astrand-Rhyming Bicycle Test

Workload	Pre-work	1	2	3	4	5	6	Rec 1	Rec 2	Mean	V02	Corr	ml/kg

$\dot{V}O_2$ MAX DATA SHEET

Name________________________

Date________________________

Time________________________

* * *

Weight (kg)____________________

Barometric Pressure__________

* * *

Speed________________________

Incline________________________

Increments____________________

Max Time______________________

Max H.R.______________________

$\dot{V}O_2$ (L/min)__________________

$\dot{V}O_2$ (ml/kg·min)________________

Bag #	Dry Gas Meter	O_2%	CO_2%	Gas Meter Temp	Vapor Tension	Time in Sec.

APPENDIX O

Gas Analysis Formula

1. $N_2 = 100 - (O_2 + CO_2)$

N_2 = percent nitrogen

O_2 = percent oxygen, measured by analyzer

CO_2 = percent carbon dioxide, measured by analyzer

2. $$STPD = \frac{PB - PH20}{760(1 + 0.00367T)}$$

STPD = correction factor for pressure and temperature

P_B = ambient barometric pressure in mmHg

PH_2O = vapor tension of water, mmHg, at the temperature of the gasometer

T = temperature of the gasometer in degrees Centigrade

3. $VN = 10(V_F - V_I)$

VN = net volume of Tissot in mm

V_F = final volume of Tissot in cm

V_I = initial volume of Tissot in cm

4. VM = (132.1) (VN) NOTE: 132.1 ml per mm

VM = volume of Tissot in ml

5. $$MA = \frac{TA}{60}$$

MA = minutes through analyzers

TA = seconds through analyzers

6. VA = MA(200 ml/min)

VA = volume of air through analyzers in ml

7. $$VE = \frac{STPD(VM + VA)}{1000}$$

VE = expired volume in liters per bag

Gas Analysis Formula (continued)

8. $$VOB = \frac{VE(0.265N_2 - O_2)}{100}$$

VOB = oxygen content per bag

9. $VO2 = VOB(60/SEC)$

VO2 = oxygen consumption in L/min

SEC = time of air collection per bag in seconds

10. $$WVO2 = \frac{VO2(1000)}{WT}$$

WVO2 = oxygen consumption in ml/kg·min

WT = weight in kilograms

APPENDIX P

THE PEARSON PRODUCT-MOMENT COEFFICIENT OF CORRELATION FORMULA

The formula for computation of correlation coefficients (90:135) was:

$$r_{xy} = \frac{n\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{n\Sigma X^2 - (\Sigma X)^2}\ \sqrt{n\Sigma Y^2 - (\Sigma Y)^2}}$$

APPPENDIX Q

Table 19

Test-Retest Reliability of Maximal and Predicted Values of VO2max

TREADMILL	TEST 1		Test 2		|X| Difference	
Subject	L/min	ml/kg·min	L/min	ml/kg·min	L/min	ml/kg·min
1T	2.54	39.20	2.61	40.05	0.07	0.85
2T	2.89	58.71	2.88	59.74	0.01	1.03
3T	2.56	44.17	2.63	45.38	0.07	1.21
4T	3.64	47.27	3.96	52.20	0.32	4.93
5T	2.40	40.00	2.32	38.69	0.08	1.31
MEAN	2.81	45.87	2.88	47.21	0.11	1.87
S.D.	0.50	7.88	0.64	8.79		
MAX BICYCLE						
1B	1.86	36.64	1.93	37.82	0.07	1.18
2B	1.73	32.90	1.77	33.64	0.04	0.74
3B	2.34	43.07	2.48	44.63	0.14	1.56
4B	2.50	38.57	2.57	39.36	0.07	0.79
5B	2.62	32.30	2.48	30.45	0.14	1.85
MEAN	2.21	36.70	2.25	37.18	0.09	1.22
S.D.	0.39	4.41	0.37	5.44		
MAX COMBINED ARM AND LEG						
1C	2.86	50.00	2.93	51.20	0.07	1.20
2C	2.53	43.59	2.29	39.60	0.24	3.99
3C	2.82	43.38	2.79	42.63	0.03	0.75
4C	3.30	40.10	3.40	41.68	0.10	1.58
5C	2.53	39.38	2.42	37.62	0.11	1.76
MEAN	2.81	43.29	2.77	42.55	0.11	1.86
S.D.	0.32	4.20	0.44	5.21		

APPENDIX R

Table 20

Test-Retest Reliability of the Combined Arm-Leg Test

Subject	Test 1 HR(bpm)	Test 2 HR(bpm)	$\bar{X}$ Difference
1SC	148	155	7
2SC	165	158	7
3SC	154	160	6
4SC	142	146	4
5SC	162	168	6
MEAN	154	157	6
S.D.	10	8	

SC = submaximal combined

Table 21

Test-Retest Reliability of the Astrand-Rhyming Bicycle Test

Subject	Test 1 HR(bpm)	Test 2 HR(bpm)	$\bar{X}$ Difference
1A	146	148	2
2A	150	142	8
3A	144	140	6
4A	148	160	12
5A	123	136	13
MEAN	142	147	8
S.D.	11	9	