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The relationship of aerobic and anaerobic capacities to performance in running

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THE RELATIONSHIP OF AEROBIC AND ANAEROBIC CAPACITIES TO PERFORMANCE IN RUNNING

By

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D.L.S.

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I. INTRODUCTION

Throughout the past three decades, there has been a great deal of emphasis placed on human performance research. The importance of performance in everyday activity has given rise to a continued growth of research in this area. In order to fully understand the meaning of performance, one must first realize the function that metabolism performs in the determination of energy for physical tasks.

Physical activity requires energy for muscular contraction. The duration and intensity at which an individual can maintain a physical performance ultimately depends upon the amount of energy the tissues can release in relation to that required. These energy yielding processes are either aerobic or anaerobic. The process is aerobic if the oxygen readily available to the tissues is equal to or greater than that required to perform the immediate work. If sufficient oxygen is not immediately available, the tissues will function by a non-oxidative process of anaerobic metabolism. Both of these processes are essential in the performance of a given physical task (25).

In metabolism, the energy producing source is the organic phosphate derivatives in muscles. Through a complex process, these phosphates are formed to produce adenosine diphosphate (ADP) which is synthesized to adenosine triphosphate (ATP) by the addition of a phosphate group. Under normal conditions the energy for this reaction is supplied by the breakdown of glucose to carbon dioxide and water, but in muscle this energy is supplied by an energy-rich phosphate compound called phosphocreatine (i.e. phosphocreatine added to ADP produces creatine plus ATP). In the aerobic process of energy production, carbohydrates (glucose) plus oxygen plus ADP are reduced through a series of chemical reactions to carbon dioxide, water and ATP. The important factor here is the production of the high energy compound ATP which is used as energy for muscular contraction (22).

A second factor of importance, other than aerobic metabolism, is the process of anaerobic metabolism. The anaerobic process is simply stated as metabolism which does not require oxygen for the production of energy for muscular activity (17). In anaerobic processes, where oxygen is not sufficient to change glucose to carbon dioxide and water, glucose breakdown ends in an intermediate reaction in which lactic acid is the end product. The lack of oxygen and the accumulation of lactic acid eventually ceases all muscular contraction if oxygen is not provided to reverse this build-up. It can be seen that, through anaerobic processes, an individual may be able to perform work for short periods of time without the presence of oxygen (24).

Oxygen consumption or the amount of oxygen taken up by the cells of the body over a given period of time, has been used for decades as a means of determining energy expenditure for physical performance. Before the turn of the century Atwater (10) experimented in the area of oxygen consumption and determined the precedent for the validity of this procedure. Karpovich (32) reported that an adequate supply of oxygen is necessary for oxidative processes in the metabolic changes from which energy is derived. Whenever more energy is required, metabolism is increased and the need for oxygen is also increased. The important factor was expressed as being the oxygen consumption rate for each individual. However, he also maintained that the oxygen level depended upon the intensity of work and the size of the muscle groups involved, being limited only by the individuals maximum capacity for oxygen intake.

During the early part of the twentieth century, a new and subsequently important concept of anaerobic work appeared in the literature. A. V. Hill (28), a pioneer in exercise physiology, coined the phrase "oxygen debt" in some of his early studies. He defined the phenomena as an insufficient amount of oxygen to meet the demands of metabolism. More recently deVries (17), explained that up to a certain level of work, where the oxygen supply is sufficient to meet the demands of exercise, there is no oxygen debt incurred. However, beyond this point, the body cannot supply enough oxygen to the working muscles and an oxygen debt is incurred. The rest period immediately after exercise is called the recovery period, and if the subject is breathing hard, he is repaying his oxygen debt. The conclusion was that because of this ability to carry on work temporarily without an adequate oxygen supply, great bursts of speed and force are possible.

The importance of this oxygen debt mechanism in athletic contests, endurance feats and emergency situations has been emphasized by physiologists and coaches. Thus, the term "oxygen debt" has become a popular concept in expressing the anaerobic process of metabolism in relation to exercise.

It is evident that these processes of metabolism have an effect on muscular activity and performance. However, it is questionable whether the aerobic processes are utilized to a greater extent during short versus long exercise than are the anaerobic processes. Many theories have been reported which suggest that a specific type of training may produce better aerobic results (longer distance efficiency); and another type of training, such as sprint training, may better develop the anaerobic mechanism of energy production. These theories, at the present time, are controversial and added research may help to discover new relationships and ideas concerning aerobic and anaerobic processes and performance in running.

II. THE PROBLEM

Statement of the Problem

The problem of this investigation was to determine the relationship of aerobic and anaerobic capacities to performance in running events. The sub-problems were the determination of the relationships between aerobic and anaerobic capacities.

Significance of the Problem

Many studies (8, 23, 26, 52) have attempted to measure or show the metabolic demands of certain exercises. However, the studies have not related these demands to a specified physical performance because of the inability to develop a reliable test. It is the purpose of this study to determine the relationship of aerobic and anaerobic capacities to performance in running. Results of such measures might then be useful in approximating success in a particular event. If the aerobic and anaerobic demands for a specific exercise were known, and if the aerobic and anaerobic capacities of a given individual were known, then one could more accurately approximate optimal performance levels, and adjust the method of exercise to most efficiently utilize the aerobic and anaerobic capacities available.

The results of this study should add to the knowledge that is already known about aerobic and anaerobic capacities. It may also show the relative importance that these capacities have in physical performance, and to what extent these capacities determine a person's ability in a specific activity.

Scope of the Study

The subjects used in this study were six male students from the University of Montana track team. They ranged in age from eighteen to twenty-two years of age and were all considered middle distance runners (880, mile, two mile). The subjects were also considered to be highly conditioned endurance athletes at the time of the study.

Limitations and Weaknesses of the Study

This study was limited to six subjects who were all track men. Because of the small number of available track athletes, it was impossible to randomly select the subjects. Therefore, the findings of this study cannot be inferred to all middle distance track athletes.

Definitions

The following terms and definitions were used in this study.

1. Aerobic Capacity--The total amount of energy available during work utilizing oxygen. The ability to take in, transport and give up oxygen to the working muscles. It is usually expressed in liters per minute or milliliters per kilogram of body weight per minute (10). A synonymous term used in this study was Maximal Oxygen Consumption. A point which is an apparent steady state during muscular exercise in which the oxygen intake may attain this maximum and remain constant, because the circulatory and respiratory systems have reached the limit of their capacities (29).
2. Anaerobic Capacity--The total amount of energy available during work without oxygen utilization. It is often defined as the maximal oxygen debt (16).
3. Oxygen Debt--Expressed as the total amount of oxygen taken up by the system during recovery in excess of basal or resting requirements (12).
4. PWC-170--An abbreviation for physical working capacity of an individual. It is expressed as

the level of work of which an individual is capable at the heart rate of 170 beats per minute. For this study the PWC-170 was calculated by submaximal heart rate tests on the bicycle ergometer (17).

CHAPTER II

REVIEW OF RELATED LITERATURE

A great deal of research dealing with the aerobic and anaerobic processes of human performance has been done in the decades since the beginning of the twentieth century. The studies that are reviewed in this chapter are those that are relevant to exercise and performance.

I. MAXIMAL OXYGEN CONSUMPTION AND EXERCISE

One of the earliest researchers in the area of exercise physiology was Atwater (10). Near the turn of the century he experimented on maximal oxygen consumption and the results of his studies have been used as prescedents for future research. Later, Hill and Lupton (30) developed some basic principles in the area of maximal oxygen consumption. They noted that each individual has a maximum level of oxygen intake per minute, that the level varies from one individual to another and that the extra work done above the maximum level of oxygen intake was done by means of anaerobic metabolism (i.e. the oxygen requirement comprises oxygen intake plus an oxygen debt). Taylor, Buskirk and Henschel (49) developed an experimental technique for measuring the maximal level of oxygen intake of an individual. This technique depended essentially upon the fact that the rate of oxygen intake, and rate of work, are linearly related up to a level of work at which a further increase in the rate of work apparently does not produce a further rise in the rate of oxygen.

Astrand and Rhyming (9) developed a nomogram in which maximal oxygen consumption could be calculated from submaximal tests. These tests consisted of taking heart rates for a single sub-maximal amount of work, and calculating on a nomogram the predicted maximal oxygen consumption. Correlation with actual experimentation was found to be as high as .83 by deVries (17).

Experimentation was conducted using maximal oxygen consumption tests as a criteria for evaluating physical fitness. Karpovich (32) reported that the degree of physical fitness depends on the individual's maximal oxygen intake. He also concluded that in order to exclude the influence of body weight, the maximal oxygen intake should be calculated per unit of body weight, usually in kilograms.

In a recent publication Cooper (13) presented a system in which the oxygen consumption values of selected activities were calculated and a point system was devised. A specific amount of points were awarded for length of time and intensity of an exercise. Intensity was determined from oxygen consumption tests. Cooper advocated that to keep in good physical condition, one must exercise at the heart rate intensity of 150 beats per minute, and that a minimum of 30 points per week (equal to 35 ml/kg/min of exercise done for 8 minutes, 6 times a week) was necessary to maintain a good level of conditioning. This conditioning was explained by Cooper as the buildup of the aerobic mechanisms of the circulatory and respiratory systems.

Many studies have found that the variation between individuals in maximal oxygen consumption was considerable. Robinson (44) found a range of maximal oxygen consumption of 0.80 to 4.50 liters per minute in males ranging from six to ninety years of age. Taylor et al. (51) found a variation in maximal oxygen consumption of five different groups (Lash, varsity track athletes, college athletes, soldiers and college students). The results indicated that Lash had 81.0 milliliters of oxygen per kilogram of body weight per minute, that track athletes had a mean value of 65.8, college athletes a mean of 52.4, soldiers a mean value of 52.9 and college students showed the lowest average for maximal oxygen consumption with a value of 44.6 milliliters of oxygen per kilogram of body weight per minute.

Robinson (43) reported that a marked improvement of aerobic capacity or maximal oxygen consumption resulted from a twenty-eight week training study that included nine men. Robinson and Harmon (45) found an improvement in the maximal oxygen consumption of twenty-five subjects after a sixteen week training program. They found that there was an average increase in maximal oxygen consumption of sixteen per cent. Londeree (36) ran tests on two groups. A pre-test for maximal oxygen consumption was performed prior to a training program. The results indicated that a seven-eights maximal training effort during interval runs of from 440-880 yards produced a higher post-test maximal oxygen consumption.

In another study, Astrand (2) ran tests on both men and women on a motor driven treadmill. The conclusions were that there was an unequivocal decrease in capacity for maximal oxygen uptake with age. Anderson (1) had similar results with his studies of carbon dioxide recovery time after moderate exercise in adults twenty to ninety years of age. He found the lowest recovery time was observed in the ages twenty to thirty. From the age of thirty on, the recovery time increased and in men was about doubled at the age of seventy, indicating a deterioration of respiratory functions, thus causing a lower maximal oxygen consumption.

In a study by Astrand and Saltin (7), six exercises were used for comparison of maximal oxygen consumption values. The exercises used were (1) cycling in sitting and supine positions (2) simultaneous arm and leg work on an ergometer (3) running on a treadmill (4) skiing (5) swimming and (6) arm work (cranking). A comparison of normal cycling in a sitting position with other types of exercise revealed an almost identical maximal oxygen consumption for combined work with arms plus legs, or an average value of 4.23 and 4.24 liters for six subjects. For running, the maximal oxygen consumption was 4.69 as compared with 4.47 liters for the same subjects examined when cycling (5% difference). Maximal oxygen consumption between one minute forty-five seconds and two minutes forty-five seconds of the treadmill run was a somewhat lower 4.54 liters. The maximal oxygen consumption in skiing was 4.48 liters as compared with 4.36 liters in the cycling experiment. Maximal cycling in a supine position gave maximal oxygen consumption of eighty per cent of that obtained during similar measurements with the subject in a sitting position. Maximal oxygen consumption averaged 3.85 and 4.47 liters respectively. In swimming, maximal oxygen consumption was eighty-seven per cent of the value obtained when cycling, absolute values being 3.79 and 4.36 liters respectively.

Lindsay (38) performed experiments on Peter Snell, a noted world champion middle distance runner and found a maximal oxygen consumption rate of 5.50 liters. Costill (14) showed similar results when working with nationally-ranked distance runners (a mean value of 4.75 liters). In a study on world class distance runners, Saltin (46) found a mean value of 5.03 liters. Kollias, Moody and Buskirk (34) found a mean oxygen consumption rate of 4.92 liters for collegiate cross-country runners.

In another study Astrand (5) found that two liters per minute may be the ceiling for an untrained man, and a trained athlete may be up in to the four liter group. He found that a Swedish skiing champion, Jernberg, had a maximal oxygen intake of 5.88 liters. Dill, Robinson and Edwards (18) in a study on distance runners, found the maximal oxygen consumption of an outstanding distance runner to be 5.35 liters per minute. In an earlier study Hill (27) found maximal oxygen consumption values above four liters among well trained and highly competative athletes.

In a study by Taylor et al. (50) some evidence was found that the ability to produce a large maximal oxygen intake or capacity may be inherited, especially in exceptionally good athletes. In a study on Lash, whose maximum oxygen intake was found to be 5.35 liters per minute, it was found that Lash's fifteen year old son had a maximal oxygen intake of 4.35 liters per minute. This was considered phenomenal because Lash's son was a non-athlete.

In a discussion by Wilt (21) concerning training for running exercises, he maintained that aerobic endurance (the ability to resist fatigue under conditions where oxygen intake and oxygen requirements are at a steady level) was more of a factor at longer distances than at shorter distances. In recommendations made by Wilt concerning training emphasis and running distances, he stipulated that in running a 100 yard dash, an emphasis of approximately two per cent is placed on the aerobic endurance factor. But, as the distance increased the percentage of aerobic endurance also increased as depicted by the value of ninety per cent aerobic endurance maintained by a marathon runner (26 miles, 385 yards).

Wilt also stated that as the distance increased, the amount of oxygen uptake (percentage of total oxygen requirement) also increased. He reported that in a 100 yard race there was no appreciable oxygen uptake, 220 yard distance showed a 5-10 per cent value, 440 yard value (46.0 seconds) was 18.5 per cent. These values increased linearly with the final value of 97.5 per cent (2 hr. 15 min.) being reported for a marathon runner.

II. ANAEROBIC WORK AND OXYGEN DEBT

A. V. Hill (28) first introduced the term "oxygen debt" in 1927. Since that time this concept has been used as one method for determining anaerobic work in physical exercise.

Simonson and Enzer (47) found that during oxygen debt the body is oxidizing materials produced during muscular exercise. The oxygen debt increased as the severity of exercise increased and eventually reached a maximum in anaerobic work, performed with maximal speed and load. They also found the amount of work performed anaerobically was proportional to the oxygen debt.

In a classic study by Margaria, Edwards and Dill (40) it was found that there was a very close association between the oxygen debt and the accumulation of lactic acid in the blood and muscles. Dill, Newman and Margaria (19) found similar results in a later study using a motor driven treadmill and exercise to exhaustion. They found that the lactic acid disappeared during recovery via oxidization to carbon dioxide and water. The authors concluded (1) the work was largely anaerobic, requiring the accumulation of an oxygen debt whose magnitude was an approximate function of time, (2) the removal rate of lactic acid was a logarithmic function of time, varying from one person to another, (3) the total oxygen debt and lactacid debt were both proportional to the duration of work.

Meyerhof (41) postulated that the oxidation of a portion of the lactic acid supplied the energy for reconverting the remainder to glycogen. However, it soon became apparent, from other studies, that the accumulation of lactic acid did not in fact cause an oxygen debt, since both are actually by-products of anaerobic metabolism.

Some recent work done by Astrand, Christiansen and their co-workers (3, 4, 11) has shown some interesting facts about the effects of intermittent work and the buildup of lactic acid in the muscles. In one experiment, a well trained subject worked for thirty seconds on a treadmill at a very high workload (4.4 liters of oxygen per minute) by alternating 5 seconds of work with 5 seconds of rest. The results showed that very little lactic acid accumulated. It was noted that even in well trained athletes a workload of that size, done continuously, would result in a large oxygen debt.

In other experiments by these same workers (3, 4, 11), subjects alternately ran ten seconds and rested five seconds for a thirty minute period and a distance of 6.67 kilometers. The results indicated a tremendous oxygen debt of 25 liters had been eliminated, in some fashion, during the 5 second rest periods. The authors also reported oxygen debts of 15 to 18 liters. The authors suggested that oxygen was stored as oxyhemoglobin in the muscles during the rest periods to support metabolism during the work periods.

A. V. Hill (28) assumed that the ratio of oxygen deficit to oxygen repayment (oxygen debt) was 1:1. This seemingly logical and simple relationship was not accepted by some investigators who found the ratio to be approximately 1:2 (37).

It has been believed that oxygen debt depended exclusively upon the excess production of lactic acid. Margaria, Edwards and Dill (40) showed this was only partly true.

They found that in a good athlete, no extra lactic acid appears in the blood during or after exercise involving an oxygen consumption of less than 2.5 liters. Knuttgen (33) found similar results when experimenting with 4 intensities (300, 700, 1000 and 1600 kgm/min) on a bicycle ergometer. He found that an oxygen debt was contracted during each intensity. However, excess lactate did not appear during the two lower intensities. Only when the oxygen consumption was 1.5 liters was there a rapid rise of lactic acid.

In 1958 Huckabee (31) reported results contrary to those of Margaria and Knuttgen. He reported that excess lactic acid appeared at all intensities of exercise and was responsible for oxygen debt. These findings reverted back to the theory of oxygen debt as Hill (28) originally conceived it.

In a later study on athletes and non-athletes Margaria et al. (39) found a higher value than Margaria, Edwards and Dill had before (40). They concluded that non-athletes would not contract an oxygen debt if the energy cost did not exceed 220 cal/kg/min (1.98 liters); a higher value was found for athletes.

As a result of these studies (31, 33, 39, 40) it was subsequently concluded that oxygen debt consists of two parts (1) alactacid and (2) lactacid. It was discovered in Margaria's study (39) that the alactacid debt is paid approximately thirty times faster than the lactacid.

Krestovnikoff reported (35) one of the largest oxygen debts ever recorded. After a 10,000 meter race, a subject accumulated an oxygen debt of 22.8 liters, a tremendously large reading.

Possible training effects in relation to oxygen debt have been reported in the literature. Londeree (36) performed experiments on a group of athletes. A pre-test for maximal oxygen debt was used and training distance of 150-250 yards at seven-eighths maximum speed was employed. A post test was administered after the training period. The results indicated that the maximal oxygen debt values increased after the training period.

Cunningham and Faulkner (15) studied the effects of training on anaerobic metabolism during a short exhaustive run. The runs were performed on a treadmill at eight miles per hour and a grade of twenty per cent. A six week training period of interval 220 yard sprints preceded the treadmill testing. Results of the short exhaustive run showed a post test increase of twenty-three per cent in running time, a nine per cent increase in oxygen debt and a seventeen per cent increase in blood lactate concentration.

In a discussion by Wilt (21) involving training for running, he hypothesized that the anaerobic endurance (ability to withstand fatigue when oxygen is in insufficient supply) seemed to be of more importance in shorter races than in longer races. In recommendations made by Wilt concerning training emphasis and running distance, he suggested that the greatest emphasis for anaerobic endurance is placed on the 880 yard run (65 per cent). As the distance increases the anaerobic emphasis decreases until a value of 5 per cent was found in the marathon. Also, as the distance decreased (from the 880) the anaerobic emphasis increased until a value of 93 per cent emphasis was found for the 100 yard dash. Speed emphasis was the other factor taken into consideration and showed values ranging from 95 per cent (100 yard dash) to 5 per cent (marathon).

Wilt also stipulated that as the distance increased, the amount of oxygen debt (percentage of total oxygen requirement) decreased. He reported that the 100 meter dash showed 100 per cent of the total oxygen requirement and the marathon showed 2.5 per cent of the total oxygen requirement. It should be noted that Wilt's statements are based on his interpretations of lifetime and practical experience rather than actual research findings.

III. SUMMARY

It is reasonably clear, as a result of the literature cited, that there are certain general principles and relationships which can be accepted. Maximal oxygen consumption varies from one individual to another. When aerobic metabolism cannot keep up the demands of muscular exercise, the anaerobic metabolism is brought in to meet the excess demands. The concept of oxygen debt is directly related to anaerobic work; in exercise of short duration performed at a maximal rate and speed, the anaerobic mechanism is possibly more utilized than the aerobic. Maximal oxygen consumption is a very good predictor of fitness and running success in middle distance races, distance races, and endurance performances. There appears to be some evidence that the ability to contract a large oxygen debt or to extend the time required to reach a maximal oxygen debt would prove to be extremely useful to endurance athletes.

It is evident that these findings are not all conclusive and that a problem still remains as to what constitutes the most effective combination of energy processes for short or long distance running. The question of how far, how much, and how fast in relationship to training is still an unknown and highly controversial subject. Several of the studies cited have suggested that certain capacities (aerobic, anaerobic) relate to specific performance levels in running. There also seems to be some evidence that an overlapping of aerobic and anaerobic processes occurrs. However, due to the relatively small amount of reliable data that has been reported reguarding these capacities, it would seem that added research is necessary concerning the interrelationship between aerobic and anaerobic capacities and performance in running.

CHAPTER III

PROCEDURE

I. THE SUBJECTS

Six subjects were selected from the track team at the University of Montana. The criteria used in the selection were that the subjects must

1. be middle distance runners
2. show an interest to participate in the study
3. be willing to participate in a series of tests both in the Human Performance Laboratory and on the track.

The subjects were given an orientation prior to the start of the program. Each subject was informed of general procedures that would be used for testing in the study. A format was given to the subjects concerning time required of each individual and the purpose and nature of the study. A description of each subjects physical characteristics appears in Table I.

II. EQUIPMENT

Bicycle Ergometer

The subjects were tested on a Monarch bicycle ergometer in the Human Performance Laboratory at the University of Montana. The bicycle ergometer was checked for calibration

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subjects	Height (inches)	Weight (pounds)	Weight (kilograms)	Age (years)
R.B.	73	164	74.6	19
T.O.	72	148	67.3	18
R.V.	68	126	57.3	21
D.S.	74	176	80.0	21
S.L.	69	134	60.9	20
M.H.	72	141	64.1	22
Means	71.3	148.1	67.3	20.2

as specified by the instructions accompanying the ergometer (6). Load was varied by either loosening or tightening the friction belt manually. Computation of desired loads will be discussed later. Figure 1 shows the Monark bicycle ergometer used in this study.

Gas Collection Apparatus

The gas collection apparatus used in this study included the following:

Collins Triple "J" breathing valve. A high volume, low resistance breathing valve allowed the subject to breath in room air and exhale through the tubing into the Douglas bag.

Hans-Rudolph four-way valve. A steel, four-way valve regulated the flow of expired air from the breathing valve to the Douglas bag.

Douglas Bag. A 200 liter rubber-lined canvas Douglas bag was used to accumulate expired air during the testing periods.

Nosepiece. A nosepiece constructed of foam rubber and wire was clamped on the subjects nostrils during testing to prevent air flow through the nose.

1 1/4 inch corrugated tubing. This plastic tubing was used to make connections between the breathing valve and four-way valve, and between the four-way valve and the Douglas bag.

Metronome. A Wittner Precision pendulum metronome was used to help the subject maintain a constant pedal rate throughout the testing period.

Stethoscope. A stethoscope was used to take heart rates before, during and after testing.

Figure 1 gives an illustration of the gas collection apparatus.

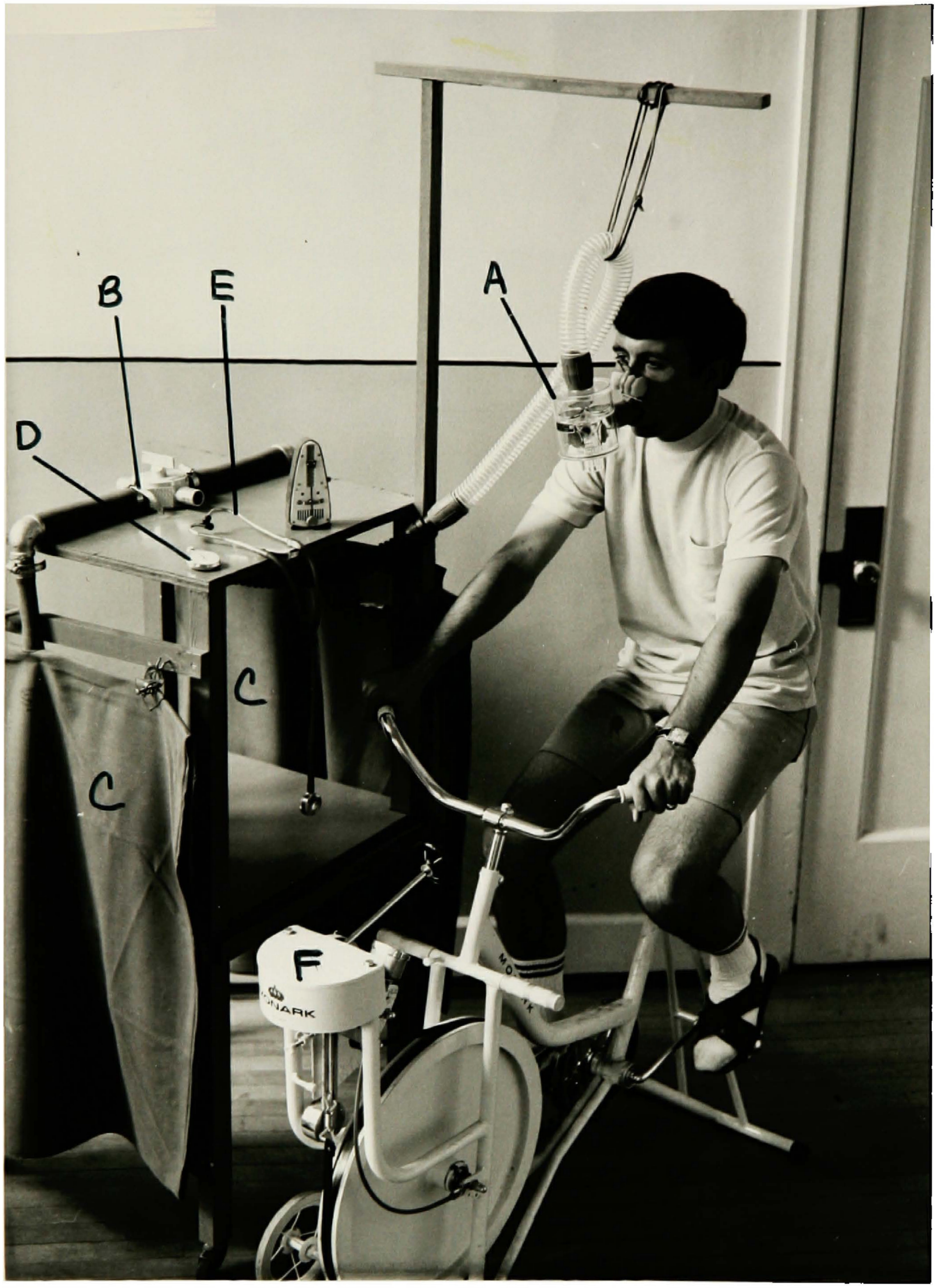


Figure 1

Front View of Subject and Apparatus

A. Collins Triple "J" Breathing Valve
B. Hans-Rudolph Four-Way Valve
C. Douglas Bags
D. Stopwatch
E. Stethoscope
F. Monark Bicycle Ergometer

Gas Analysis Apparatus

The instruments used to make the necessary gas analysis for the maximal oxygen consumption text included:

Bailey Bottle. This bottle consisted of two glass tubes with a mercury balance and a two-way valve on top. The bottle was used to transfer the expired test gas from the Douglas bag to the gas partitioner.

Chain-Compensated Wet Gasometer. A 600 liter capacity gasometer was used in the study and consisted of a water filled metal cylinder with a cone-shaped inner cylinder. A sliding scale was attached to the side of the gasometer which measured the volume of air evacuated into the gasometer from the Douglas bag. A centigrade thermometer was attached to the gasometer with a range from 0° to 40° centigrade. The thermometer was used to find the temperature of the sample gases.

Fisher-Hamilton Gas Partitioner. Sample gases were introduced via an inlet port into a 0.25 milliliter sample loop. From there a continous flow of helium carrier gas swept the test gas through two chromatographic columns. The columns were packed with an absorbent which selectively retarded various components of the sample. The components (oxygen, nitrogen and carbon dioxide) were therefore separated and eluted from the system at different times. As each component was eluted, a heated filament detector sensed its thermal conductivity and altered the balance in a bridge circuit. The electrical signal was then sent to the recorder.

Recorder. A one millivolt (1 mv) Texas Instrument recorder was used in the gas analysis procedure. The full scale pen response was less than 0.5 seconds. The chart speed was variable. The chart grid width measured 9.50 inches. The instrument recorded the electrical impulses sent from the gas partitioner in the form of chromatographic peaks. Percentages for each reference gas were calculated from a conversion curve which will be discussed later.

Scholander Micrometer Gas Analyzer. The apparatus consisted of a reaction chamber unit which contained a compensating chamber, reaction chamber and two chambers for storing absorbents for carbon dioxide and oxygen. A small amount of respiratory gas was introduced into the instrument to obtain estimated oxygen and carbon dioxide values. The Scholander instrument was used in this study to determine the precise composition of the reference gases.

Reference Tanks. There were two reference gases used in this study. Reference tank number one consisted of 5.02 per cent carbon dioxide and 15.24 per cent oxygen. Reference tank number two consisted of 2.42 per cent carbon dioxide and 18.45 per cent oxygen. These reference gases were used to plot graph lines for conversion of peak heights to per cent composition.

Carrier Gas. Helium was used as a carrier gas for the Fisher-Hamilton gas partitioner. A uniform flow rate of forty milliliters per minute was maintained and calibrated by a bubble tower assembly. This assembly allowed a bubble to rise up a scale tube at the rate of the helium carrier flow. At forty milliliters per minute it took fifteen seconds for the bubble to rise ten centimeters in the tube. Helium carrier flow was checked before each gas analysis.

Stop watches. Thirty second watches were used in the maximal oxygen consumption tests, the anaerobic tests and in the performance tests.

Figure 2 shows the gas analysis apparatus used in the study.

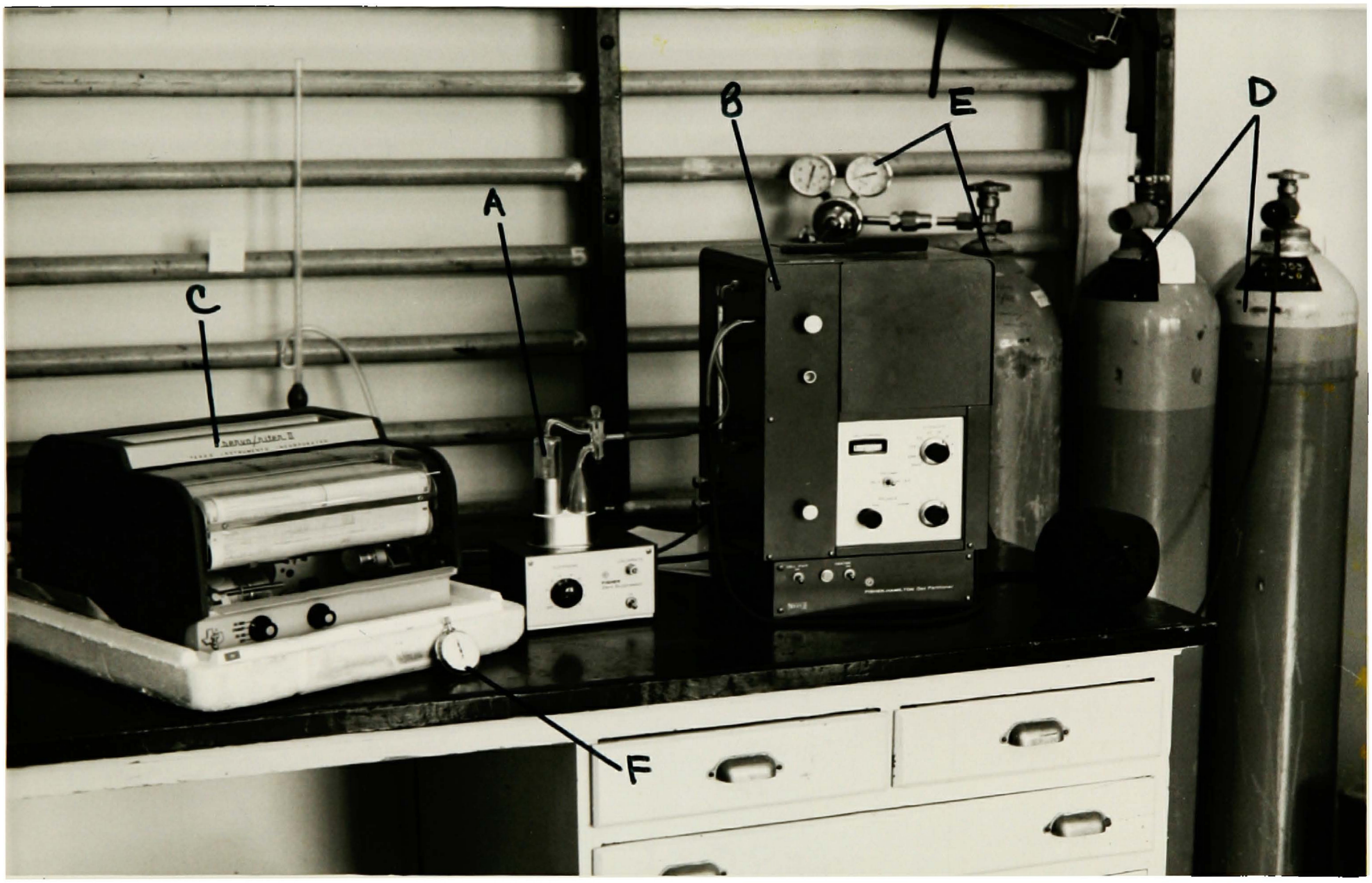


Figure 2

Gas Analysis Apparatus

A. Bailey Bottle
B. Fisher-Hamilton Gas Partitioner
C. Recorder
D. Reference Gas Tanks
E. Helium Carrier Gas Tank and Regulator
F. Stopwatch

III. TESTING PROCEDURE

A. MAXIMAL OXYGEN CONSUMPTION TEST

A pilot study was conducted over a period of approximately three weeks. This period of time provided the subjects with ample training with respect to the apparatus and procedures. At the end of the three weeks the subjects were assigned testing times.

Calculation of Bicycle Ergometer Work Load

The work load was calculated according to the procedure described by Astrand (6). The gearing and circumference of the wheel of the Monark bicycle ergometer were so dimensioned that with a pedal rate of fifty revolutions per minute the "track distance" covered was 300 meters. When tension was applied to the belt surrounding the flywheel, the deflection of the pendulum scale read the units in kiloponds (kp). (One kp is the force acting on the mass of one kg at normal acceleration of gravity). The braking power (kp) set by adjustment of belt tension, multiplied by distance pedalled (m) gave the amount of work in kilopond meters (kpm). When the work was expressed per minute, then the rate of work in kpm per minute was obtained. Using these figures, but recalculating for sixty pedal turns per minute, it was found that one kp on the ergometer scale was equal to 362.34 kpm per minute. The work load for eighty pedal turns was also utilized in the study. This was calculated as one kp on the ergometer scale being equal to 483.12 kpm per minute.

Sjostrand Test

At the beginning of the study the subjects had been instructed to wear their regular work out clothing for the tests. Prior to the start of the testing period, each subject was asked to remove his shoes and outer clothing (warm up suit) so that he wore only his socks, shorts and shirt. He was then weighed and his weight recorded to the nearest pound. The subject was then asked to sit in a chair and was questioned about information pertinent to the study. If the subject had not done any exercise for at least one-half hour, his heart rate was taken after approximately ten minutes of rest. If the subject had done minor exercise within thirty minutes prior to his arrival, he was allowed to rest from fifteen to twenty-five minutes. At the end of this time his heart rate was taken and this value was recorded as the resting heart rate for the test.

After determining the resting pulse rate, the subject was asked to seat himself on the bicycle ergometer. The seat height was adjusted by having only slight extension of the knee when the pedal was at its bottom swing. Once adjusted, the seat height remained the same for subsequent tests.

The Sjostrand Test (48) was then administered to the subject. This test began with a six minute ride. The metronome was set for sixty revolutions per minute and the load was set at 450 kpm per minute (1.25 on the ergometer scale). The stop watch was started when the subject began to pedal. Each subject was watched carefully and was prompted to maintain the sixty revolution speed as close as possible. After five minutes and forty-five seconds the subjects heart rate was taken by stethoscope and recorded; the ride ended after the six minute period was over. The subject was then asked to get off the bicycle and sit in a chair until his heart rate returned to within twelve beats of the resting pulse rate taken at the start of the testing session.

The procedure for the second test ride was exactly the same as the first, except the load was set at 900 kpm per minute (2.50 on the ergometer scale). The metronome was maintained at sixty revolutions per minute. The heart rate was again taken near the end of the test ride and was recorded. The subject was allowed to rest until his heart rate returned to within twelve beats of the resting heart rate.

These two rides were used as a warm up procedure for the maximal oxygen consumption test and also as a means of predicting the physical working capacity (PWC-170) for each subject.

PWC-170 Test

The Sjostrand Test was used to determine the physical working capacity of each subject. The working capacity was calculated by plotting graphically the heart rate and the work load at the end of each trial. A straight line was drawn through the two points to intersect the line of 170 beats per minute. The estimated amount of work that corresponds to a heart rate of 170 was then recorded as the individuals PWC-170 (17). Table II and Appendix A show the PWC-170 for each subject.

Maximal Oxygen Consumption Test

After the two six minute warm up rides and when the subject's heart rate had returned to within twelve beats of his resting pulse rate, the subject was again seated on the bicycle ergometer. The maximal oxygen consumption test administered was similar to that of Taylor, Buskirk and Henschel (49). The subject inhaled and exhaled through a Collins Triple "J" breathing valve by means of a rubber mouthpiece. The nose was completely closed with a nasal clamp. The breathing valve was connected to a Hans-Rudolph four-way valve by a 1 1/4 inch (ID) piece of corrugated plastic hose. A similar piece of hose connected the outlet of the four-way valve to a 200 liter Douglas bag.

Since Astrand and Saltin (8) found that a period of two minutes of very heavy exercise following a ten minute warm up was sufficient to bring about maximal oxygen intake in young, healthy and well trained individuals, two and one-half to three minute test rides were used.

The first test ride was set at 250 kpm per minute above the PWC-170 as determined by the Sjostrand Test. The metronome was maintained at sixty revolutions per minute and a stop watch was started by the investigator at the commencement of pedalling by the subject. At the end of the second minute of exercise the subject's respiratory air was diverted into the Douglas bag via the four-way valve and a one minute gas sample was collected. After two minutes and forty-five seconds of exercise the heart rate was recorded for that test. The exercise was terminated after three minutes. The subject was then allowed to rest as described previously.

The procedure for the second and third test rides was the same as the first, except that the load increased in increments of 250 kpm per minute for each subsequent ride. In some few cases where the work load was extremely difficult, thirty second samples were taken. The samples were always taken after at least two minutes of riding time. In some cases it was necessary to change the pedal rate to eighty revolutions per minute and recalculate the load so the amount of work remained the same. This was done when a subject had reached the point where a further increase could not be tolerated after the second ride. It was found that the increased resistance did not allow enough exercise time (two minutes minimum) for the oxygen consumption to level off at the maximal peak. Table II shows the results of the maximum oxygen consumption tests.

Collection of Gas

The expired gas was accumulated in a 200 liter Douglas bag. The Douglas bag had been vacuumed before the start of the days testing and was flushed for each subsequent test. During the first two minutes of testing the subject exhaled into the atmosphere through the collection system, but after this time, the subject exhaled through the system into a Douglas bag. In most cases one minute samples were taken, but in some of the higher testing loads, thrity second samples were collected.

Gas Analysis Procedure

The Fisher-Hamilton gas partitioner was calibrated for each experiment by conducting analysis of two reference gases both before and after the respiratory gas samples. These gases gave reference points of 15.24 and 18.45 per cent oxygen, with 5.02 and 2.42 per cent carbon dioxide. The duplicate analysis of each gas yielded only slight differences in chart unit values. In order to change chart

Table II

MAXIMUM OXYGEN CONSUMPTION TEST ON ERGOMETER

Test	Subjects	Date	PWC-170	KPM	Ergometer Scale	Maximum Heart Rate
	M.H.	3/8/69	1590	1840	5.07	156
	R.V.	3/8/69	1490	1740	4.80	168
Test 1	R.B.	3/7/69	1400	1650	4.55	140
	S.L.	3/8/69	1290	1540	4.25	164
	D.S.	3/7/69	1360	1610	4.44	156
	T.O.	3/7/69	1140	1390	3.83	152
	M.H.	3/8/69		2090	5.75	188
	R.V.	3/8/69		1990	5.50	180
Test 2	R.B.	3/7/69		1900	5.24	168
	S.L.	3/8/69		1790	4.94	176
	D.S.	3/7/69		1860	5.13	168
	T.O.	3/7/69		1640	4.52	168
	M.H.	3/11/69		2090*	4.32*	192
	R.V.	3/11/69		1990*	4.12*	180
Test 3	R.B.	3/7/69		2150	5.93	172
	S.L.	3/8/69		2040	5.63	180
	D.S.	3/7/69		2110	5.80	176
	T.O.	3/7/69		1890	3.91	180

*Metronome set at 80 revolutions/minute and resistance adjusted lines into per cent it was necessary to construct a graph using the reference gas values as points for the computation line. In as much as each days reference gas chart values changed somewhat, it became necessary to make a new graph for each testing period. This was done for both carbon dioxide and oxygen values. The treatment of this data is explained in a later section.

A Bailey bottle was used to remove the sample gas from the Douglas bags via a small tube of approximately one-fourth inch (ID). This sample was then introduced into the gas partitioner by connecting the tube to the partitioner. The Bailey bottle was opened slowly, letting gas pass into the partitioner. The plunger knob of the partitioner was pressed and the sample was swept into the dual columns by the helium carrier gas. Duplicate samples were introduced similarly.

After the samples had been taken from the Douglas bags for analysis, each bag was exhausted into the gasometer and the volume recorded. The temperature of the gas was taken at this time and the barometric pressure recorded.

Determination of Ventilation Rate

A chain-compensated wet gasometer with a 600 liter capacity was used in this study. Before the respiratory gas was inserted into the gasometer, the pre-test scale reading was recorded. The respiratory gas was then introduced and when the Douglas bag was completely empty, the post-test reading was recorded. The difference in the two readings was recorded. At this point it was necessary to multiply the difference by the gasometer factor (5.158 cm) to give the volume of the samples. This was done because the gasometer scale recorded in millimeter units. The sample volume was then multiplied by the conversion factor, derived from the barometric pressure in millimeters of mercury and the temperature of the test gas in degrees centigrade. A nomogram developed by Robert C. Darling (12) was used for this purpose. The ventilation rate (VR) for each collection was recorded in liters per minute to the nearest one-hundredth of one liter by simply dividing the total corrected volume by the number of minutes in the collection period. A simple formula for this reads:

$$\text{post} - \text{pre} = \text{diff.} \times \underset{\text{factor}}{\text{gasometer}} \times \underset{\text{factor}}{\text{conversion}} =$$

$$\frac{\text{total corrected volume}}{100} = \text{Ventilation Rate (liters/min)}$$

<u>Determination of Oxygen and Carbon Dioxide Per Cent</u>

Two reference gases were analyzed both before and after analysis of the respiratory gases for each experiment. For each reference gas the average of two trial peak heights was plotted against the known per cent of oxygen and carbon dioxide to provide the conversion curve for that experiment. This was done on separate graphs. It was found that there was very little difference between conversion curves from one experiment to another.

The respiratory gases were analyzed in duplicate. The mean peak heights for oxygen and carbon dioxide were applied to the reference curve to convert the chart lines to per cent of the sample gas. However, since the subjects breathed room air containing argon, it was necessary to correct each mean oxygen peak for argon interference in order toobtain actual oxygen per cent. The argon correction factor developed by Hamilton (42) was used for this purpose. Hamilton found that when breathing room air there must be a correction factor for argon because the analysis apparatus records argon along with the oxygen value. The formula he developed was:

$$\text{corrected } \% \ O_2 = \text{uncorrected } \% \ O_2 - 0.80$$

Therefore, 0.80 was subtracted from the uncorrected oxygen concentration to determine the actual percentage of oxygen. This value was recorded to the nearest hundredth of one per cent.

Determination of Oxygen Consumption

After obtaining the percentages of oxygen and carbon dioxide, the nomogram developed by Dill et al. (12) was utilized to gain further values. By inserting the values found for oxygen and carbon dioxide, the respiratory quotient and true oxygen were calculated and recorded. The true oxygen was then multiplied by the ventilation rate (VR) and this value was divided by one hundred to give the oxygen consumption in liters per minute. The formula used in this study was:

$$Vo_2 \text{ (liters/min)} = \frac{\text{Vgas (liters/min)} \times \text{true } O_2}{100}$$

<u>Determination of Maximal Oxygen Consumption</u>

After obtaining oxygen consumption values for each testing period, it became necessary to calculate this data in milliliters per kilogram of body weight per minute (ml/kg/min). Each subjects body weight was converted into kilograms by dividing pounds by 2.2 (1 kg). The maximal oxygen consumption was taken as that value which turned down with increasing load or that value which showed less than 150 milliliter increment over the preceding test (49). Tabulation of this data appears in Table III and Appendix B.

B. ANAEROBIC TESTING PROCEDURE

The test used for determining anaerobic capacity was under development by David A. Dainty (16). The same subjects were used in Dainty's study. Only a brief description of the

TABLE III

MAXIMAL OXYGEN CONSUMPTION

Subjects	Ventilation Rate (lit/min)	Oxygen (lit/min)	Oxygen ml/kg/min
M.H.	101.84	4.1080	64.09
R.V.	106.32	3.6574	63.86
R.B.	115.51	4.6666	62.59
S.L.	89.24	3.7302	61.25
D.S.	137.85	4.4801	56.00
T.O.	79.72	3.3243	49.42

procedure will be mentioned here.

A pilot test was conducted over a two week period. This test was made on the same Monark bicycle ergometer that was used in the aerobic tests. The objective was to try and determine the rate and load which best tested each subjects capacity for anaerobic work. The three different rate and loads were:

1. 4.5 kpm x 80 rpm
2. 4.0 kpm x 80 rpm
3. 4.0 kpm x 90 rpm

Each of these tests was administered while the subject was holding his breath for the longest possible time while working. Therefore, the rate and load at which the subject could hold his breath and accumulate the highest work out put was taken as the best level of anaerobic work. Once this had been determined the actual test was administered (at least one day later).

The subjects were connected to the breathing apparatus described in the aerobic (maximal oxygen consumption) test. The same procedure was used as in the pilot test, except recovery air samples (seven minutes) were taken when the subject could no longer continue the work while holding his breath. At this time the respiratory air was accumulated in the Douglas bags and a sample was taken and analyzed by the gas partitioner. An oxygen debt value was calculated and the data recorded for use in both studies. The amount of work performed during the test was also recorded (kpm). Table IV shows the results of the anaerobic gas analysis for the subjects. A more complete analysis is found in Appendix C.

C. PERFORMANCE TESTS PROCEDURE

The performance tests selected for this study were 330 yards, 660 yards, 880 yards, 1320 yards and the mile run. Only the 330, 660, and 1320 yard runs were designated as experiment tests. Data for the 880 and mile run were taken as best recorded times of the year. The testing was done on the rubber-asphalt track at the University of Montana. The subjects had trained all season on the track under the supervision of the investigator. Test runs were made at least one day apart. Temperature and wind readings were recorded each day testing was conducted.

330, 660 and 1320 Yard Tests

The subjects were asked to report to the track at the regular workout time of 3:30 p.m. on May 20, 21 and 22. They were told to warm up and prepare themselves as if it were a meet day. Each subject was informed two days earlier that he would run the test as a time trial. This was done

TABLE IV

ANAEROBIC WORK TEST DATA (O_2 DEBT)

Subjects	Ventilation Rate(l/min)	O_2 Debt Lit/min	O_2 Debt ml/kg/min	KPM/KG	KPM	Ratio
M.H.	27.64	.815	12.91	23.22	1467	5.04
R.V.	23.56	.706	12.44	21.22	1206	5.18
R.B.	21.07	.684	9.54	18.31	1467	6.81
S.L.	16.80	.479	7.81	20.37	1463	7.79
D.S.	24.65	.665	8.51	17.71	1641	6.73
T.O.	18.17	.599	8.85	20.15	1375	5.58

to get the subjects mentally ready for the tests and to help insure the best possible effort from each subject.

Each day after the warmup, the subjects were called to the starting line where they randomly selected their lanes. The starting procedure for each race was essentially the same. At the command of the starter the subjects came to the line and a gun started the test. The start and the race were designed to follow the exact procedure used in a meet. At the finish line there were six officials who had been assigned a specific place to time. The testing for that day was concluded when the officials recorded their times with the investigator.

880 Yard and Mile Run Test

In this study the 880 yard run and mile run data were taken as the best times posted by the subject during the competitive year. There were no time trials in these two events because times under such a competitive experience as a meet were thought to be as valid, or more valid, than a time trial. The results of the performance tests may be found in Table V.

TABLE V

PERFORMANCE TESTS

Subject	330 yd Test	660 yd Test	880 yd	1320 yd Test	mile run
M.H.	36.9*	80.3	110.6	190.6	257.9
R.V.	38.2	82.0	112.0	190.6	258.6
R.B.	38.5	86.9	-----**	192.5	-----
S.L.	39.5	86.1	116.0	192.6	261.4
D.S.	37.6	85.2	115.7	193.5	-----
T.O.	38.9	85.3	118.0	194.6	263.5

*All times were recorded to the nearest 0.1 second.
**No time available.

CHAPTER IV

RESULTS, DISCUSSION AND SUGGESTIONS

I. RESULTS OF THE MAXIMAL OXYGEN CONSUMPTION TEST

Table III indicates the aerobic capacity for the subjects in liters per minute and milliliters per kilogram of body weight per minute. In a study by Taylor et al. (51) it was found that the mean oxygen intake for collegiate track athletes was 65.8 milliliters per kilogram per minute. The values found in Table III show a mean of 59.5 milliliters per kilogram per minute, slightly lower than those reported by Taylor. A probable explanation for the difference may be in the size of the groups and the apparatus used to determine the maximal oxygen consumption. In Taylor's study there were fifteen subjects tested on a treadmill as compared to six subjects tested on a bicycle ergometer in this investigation. Several studies have shown a higher value for maximal oxygen consumption using a treadmill versus a bicycle ergometer.

The maximal oxygen consumption data ranged from 49.42 to 64.09 milliliters per kilogram per minute. This range appears to be fairly large when considering that all of the subjects were highly trained athletes. However, many studies have shown a substantial variation in even the most highly trained athletes (5, 7, 18, 27). Other data such as heart rate and work load may be found in Table II.

II. RESULTS OF THE ANAEROBIC TEST

The anaerobic test data was taken from the study by Dainty (16). The anaerobic values ranged from 7.81 to 12.91 milliliters of oxygen per kilogram per minute. Expressed in liters these values ranged from .479 to .815 liters per minute. These values were expressed as the gross oxygen debt for the subjects. The amount of work was measured in kpm per kilogram of body weight for the anaerobic test. The values ranged from 17.71 to 23.22 kilopond meters per minute per kilogram. It was impossible to make a comparision for oxygen debt with other studies due to the fact that the anaerobic test used in Dainty's study was developed using different procedures and methods than were used by other investigators (eg. a short duration of work and shorter recovery collection). His procedure was an attempt to develop a simplified test for anaerobic capacity.

III. RESULTS OF THE PERFORMANCE TESTS

The performance tests used in this study were five specific races performed on a rubber-asphalt track. The results were recorded in seconds and tenths of seconds. Subject M.H. achieved the lowest times in every test.

Subject R.V. achieved the second lowest scores in each test run. Table V shows a complete collection of recorded times for the performance tests. It should be noted that the lower times indicate superior performances.

IV. RELATIONSHIP BETWEEN AEROBIC CAPACITY AND PERFORMANCE

The results of the aerobic capacity test and each performance test were correlated using the Spearman-Rho rank-order correlation method (20). The value used for aerobic capacity was expressed as milliliters of oxygen per kilogram of body weight per minute (ml/kg/min). The performance scores were expressed as total seconds to a tenth of a second. The results showed the following correlations between aerobic capacity and performance:

330 yard run and Aerobic Capacity	Rho = .543	(n = 6)
660 yard run and Aerobic Capacity	Rho = .486	(n = 6)
880 yard run and Aerobic Capacity	Rho = .900	(n = 5)
1320 yard run and Aerobic Capacity	Rho = .986	(n = 6)
mile run and Aerobic Capacity	Rho = 1.000	(n = 4)

In the 880 and mile run, the number (n) for each test was smaller because best recorded times of the year were taken. Subject R.B. did not have a recorded time in the 880 yard run and subjects R.B. and D.S. had no times in the mile run. Figures 3, 4, 5, 6 and 7 shows the relationship of the aerobic capacity values and time in the performance tests.

V. RELATIONSHIP BETWEEN ANAEROBIC CAPACITY AND PERFORMANCE

A Spearman-Rho rank-order correlation was made between anaerobic capacity and each performance test. The value used as anaerobic capacity was expressed in milliliters per kilogram of body weight per minute (ml/kg/min). The performances were expressed as seconds to the nearest tenth of a second. The correlations between anaerobic capacity and performance were:

330 yard run and Anaerobic Capacity	Rho = .658 (n = 6)
660 yard run and Anaerobic Capacity	Rho = .600 (n = 6)
880 yard run and Anaerobic Capacity	Rho = .700 (n = 5)
1320 yard run and Anaerobic Capacity	Rho = .758 (n = 6)
mile run and Anaerobic Capacity	Rho = .800 (n = 4)

The results suggest that there is a stronger relationship between anaerobic capacity and the mile run (.800) than between anaerobic capacity and the 300 yard run (.658). There is also a gradual increase in relationship as the distance increases. These findings cast some doubt on the use of oxygen debt data derived from Dainty's anaerobic test as a measure of anaerobic capacity. A graphic illus-

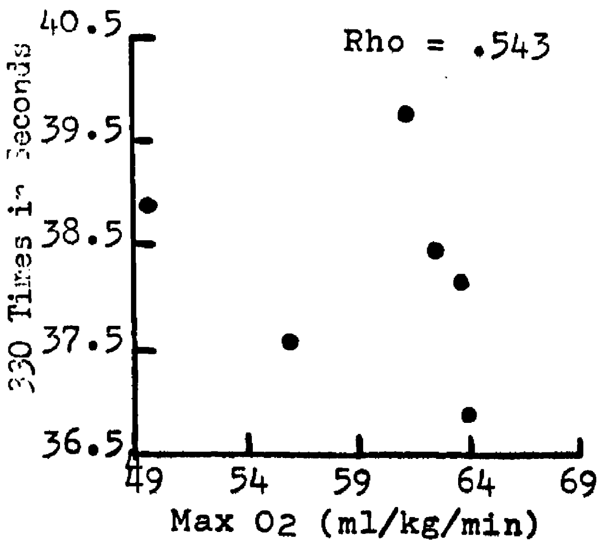


Figure 3

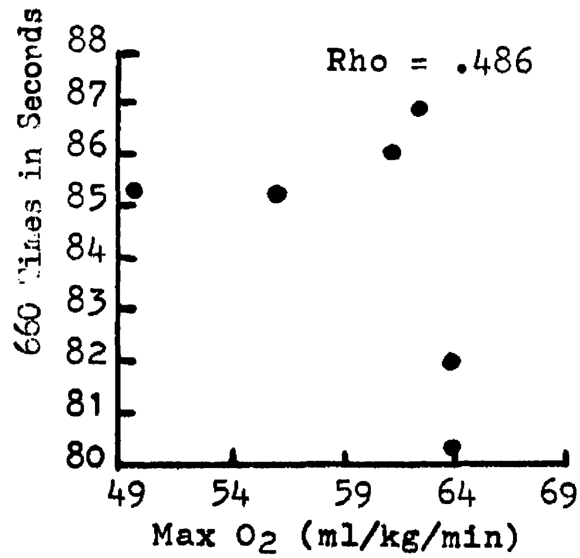


Figure 4

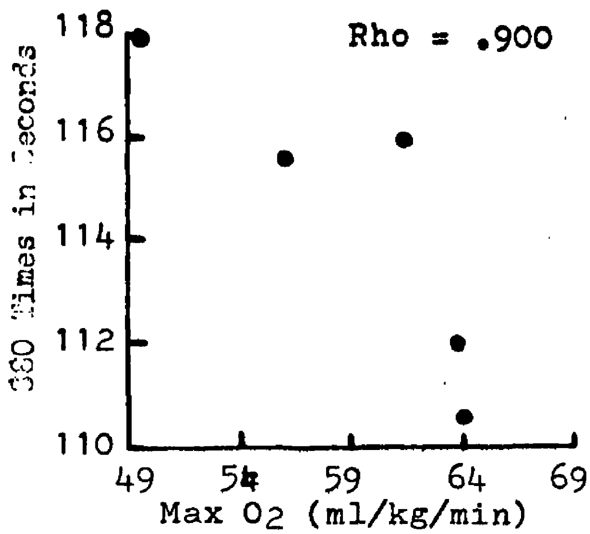
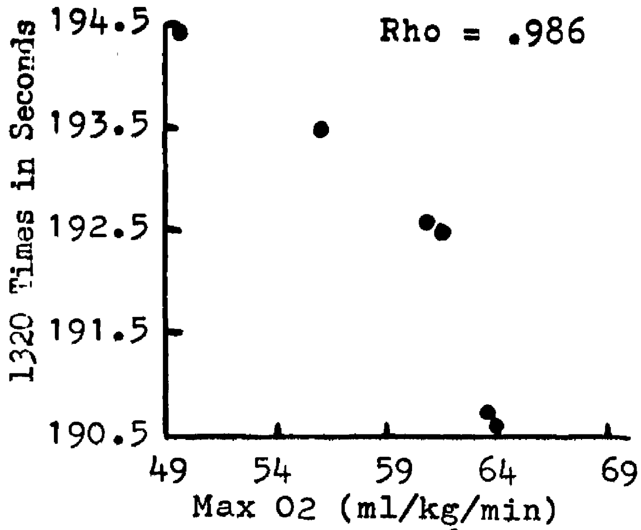


Figure 5



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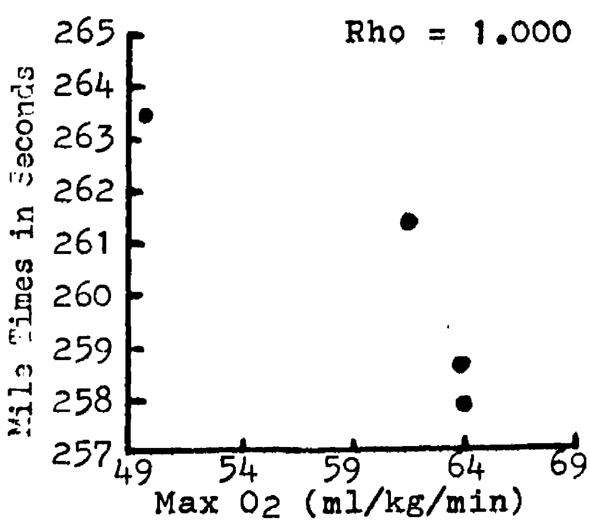

Figure 7

tration of this data may be found in Figures 8, 9, 10, 11 and 12.

VI. RELATIONSHIP BETWEEN AEROBIC/ANAEROBIC RATIO AND PERFORMANCE

A ratio was made between the aerobic and anaerobic capacities in order to attempt a composite relationship between these two capacities and performance. A Spearman-Rho rank-order correlation was made between the aerobic/anaerobic ratio and performance. The following are the results of the correlations between the ratio and performance:

330 yard and aerobic/anaerobic ratio	Rho = .715 (n = 6)
660 yard and aerobic/anaerobic ratio	Rho = .886 (n = 6)
880 yard and aerobic/anaerobic ratio	Rho = .700 (n = 5)
1320 yard and aerobic/anaerobic ratio	Rho = .415 (n = 6)
mile and aerobic/anaerobic ratio	Rho = .800 (n = 4)

The results show there is a good relationship between the aerobic/anaerobic ratio and the 330, 660, 880 and mile run. The correlation between the aerobic/anaerobic ratio and 1320 yard run was somewhat lower, with a coefficient of .415. Figures 13, 14, 15, 16 and 17 illustrate the relationships.

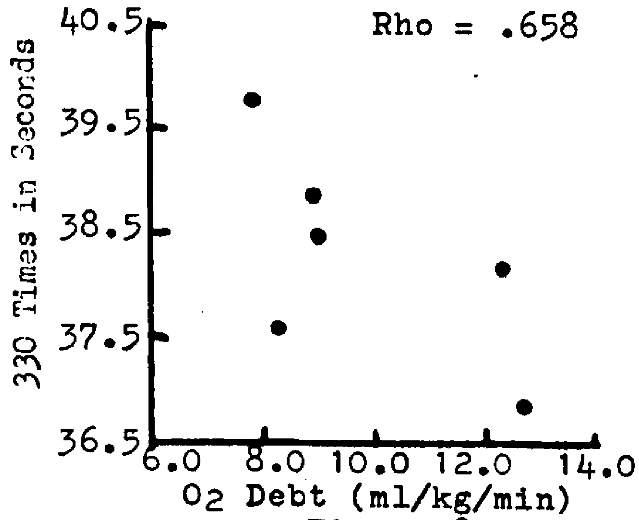

Figure 8

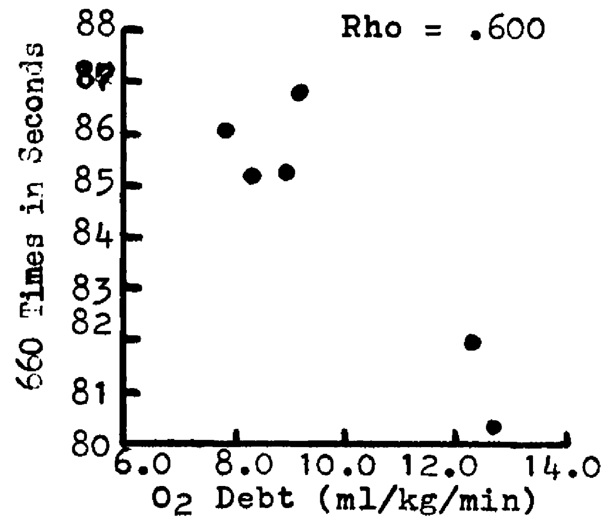

Figure 9

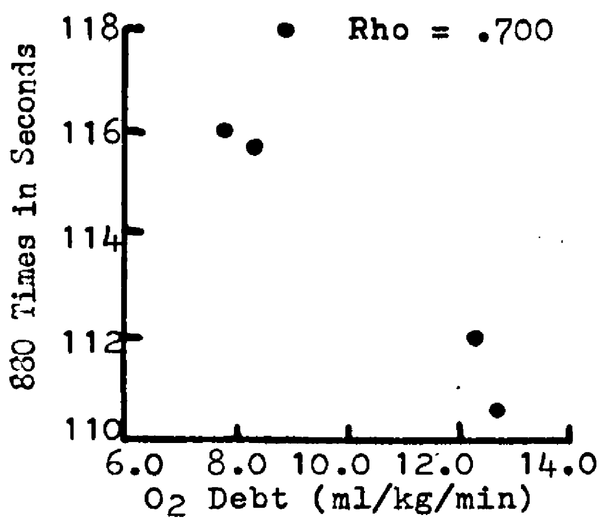

Figure 10

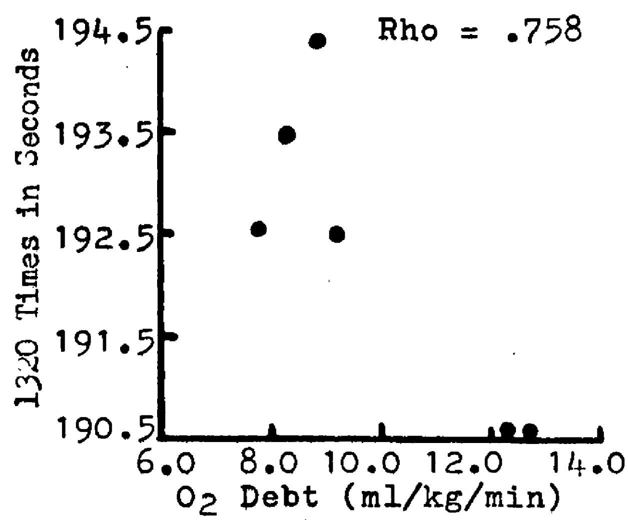

Figure 11

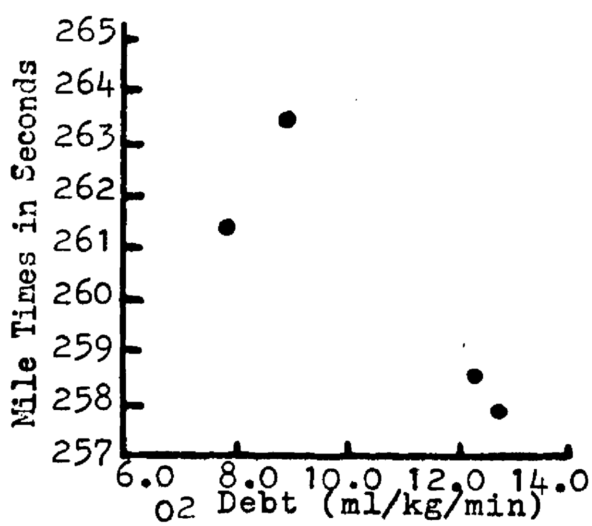

Figure 12

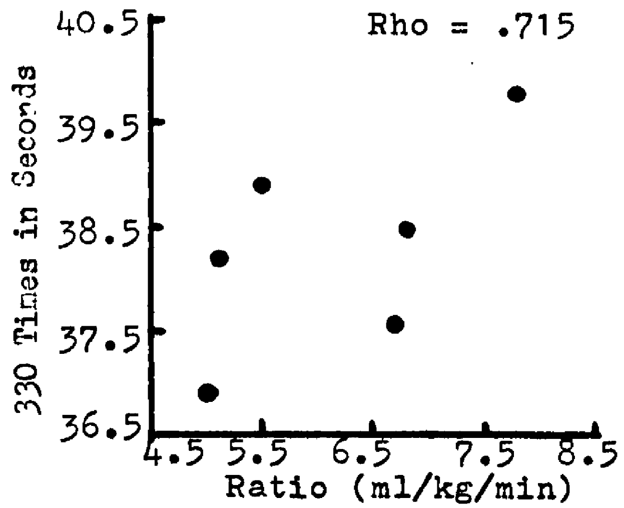

Figure 13

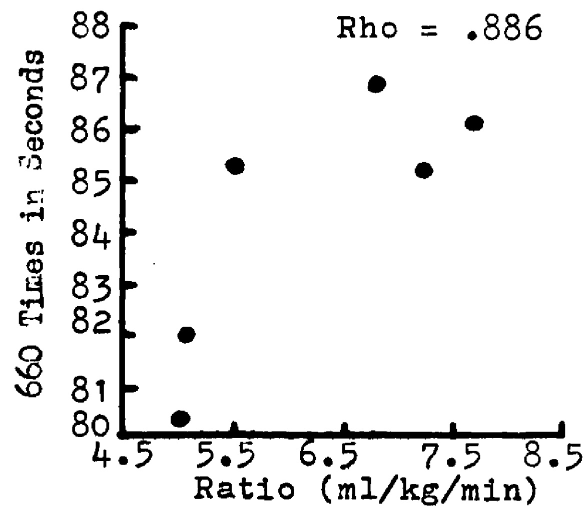

Figure 14

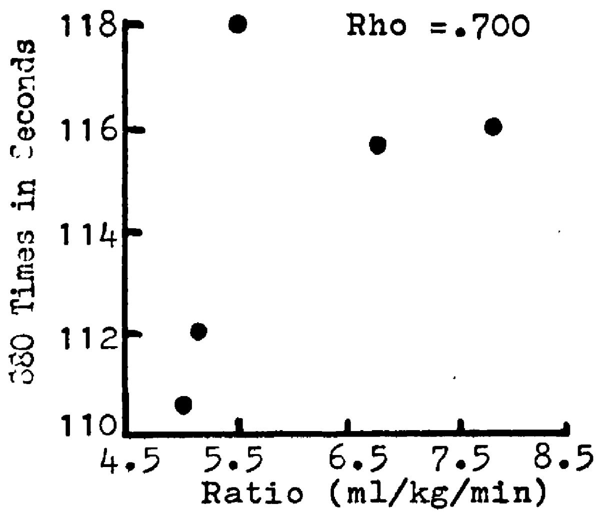

Figure 15

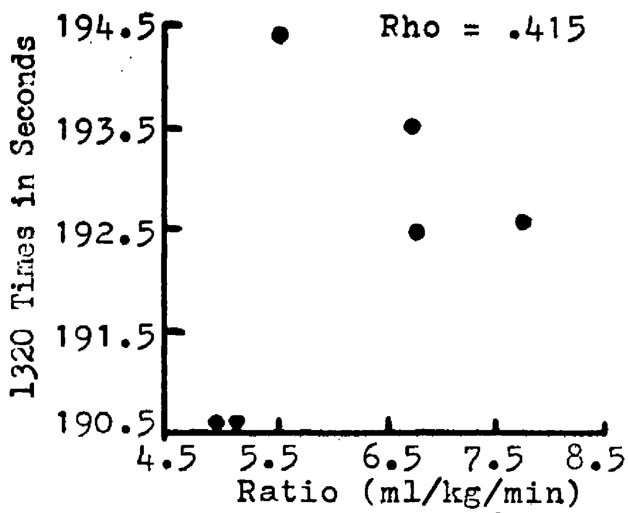

Figure 16

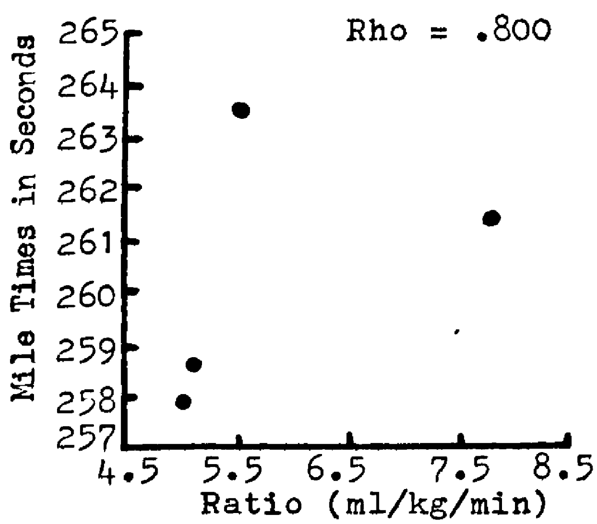

Figure 17

VII. DISCUSSION

The results of the maximal oxygen consumption test showed a range of 49.29 to 64.09 ml/kg/min. Such a large range in aerobic capacity is not unusual, however, even in well trained athletes. The mean of 59.5 milliliters per kilogram per minute found in this study is substantially lower than the results of Taylor et al. (51) and Costill (14). However, it was found in a study by Astrand and Saltin (7) that a difference of approximately 5% was found when comparing the maximal oxygen consumption of track athletes for running and that of cycling (67.1 and 63.5 ml/kg/min respectively). Therefore, the mean value (59.5 ml/kg/min) found in this study using a bicycle ergometer is comparable to the results reported by Taylor et al. (51) and Costill (14) who utilized treadmills in their testing procedures (treadmill values were higher due to the larger muscle mass and body weight involved).

An attempt was made in this study to determine the relationship between the physical working capacity (PWC-170) and performance. The results of these correlations showed a similar relationship as that found between aerobic capacity and performance (i.e. as the distance increased the correlation between PWC-170 and performance increased). In view of these findings, a correlation was calculated between aerobic capacity and PWC-170 to find the relationships between these two variables. The results showed a near perfect correlation (Rho = .943) existed between aerobic capacity and PWC-170. This correlation seems to corroborate findings that suggest there is a close relationship between aerobic capacity and physical working capacity.

There appears to be a very good linear relationship between aerobic capacity and running the 330, 660, 880, 1320 and mile run. Wilt (21) has suggested that as the running distance increases the amount of emphasis placed on aerobic metabolism (oxygen uptake) is increased also. The results found in this study seems to corroborate Wilt's suggestion. The results in this study showed a fair correlation between aerobic capacity and 330 (.54 or approximately 29% of the variance accounted for) and the relationship increased with each running distance, with the final test (mile run) showing a perfect correlation (1.000). In comparison, Wilt's data suggested that in a 330 yard run (thirty-six seconds), approximately fifteen per cent of the total oxygen requirement involved the aerobic mechanism, and at the end of a mile run (four minutes) approximately fifty-five per cent was aerobic. Thus, he showed similar results of an increase from one running distance to the next. It is apparent from this study that a higher correlation exists between aerobic capacity and performance as the distance increases. This is understandable from the theoretical point of view since the longer the race, the more oxygen is necessary for metabolism. Since the rate of exercise is slower in a longer race, it is possible to meet more of the demands with aerobic metabolism. These results support the hypothesis that a person with a higher aerobic capacity is able to perform better at a longer distance than a person with a lower aerobic capacity.

The method for determination of anaerobic capacity was developed by Dainty (16). The results showed a range in oxygen debt from 7.81 to 12.91 milliliters per kilogram per minute. Since the amount of time for the anaerobic test was relatively short, the oxygen debt values were small. It was, therefore, impossible to compare this data with results of other studies.

It appears that there may be a good relationship between the aerobic/anaerobic ratio and performance. The results of this study have shown a very high positive correlation between the aerobic/anaerobic ratio and time in running. It has been hypothesized that the aerobic and anaerobic processes do not function separately during exercise. However, it has been suggested by Wilt (21) that at certain distances, stress is placed on either the aerobic or anaerobic mechanism. The composite value obtained in this study was an attempt to find the relationship between these two capacities (combined) and races of different distances. It is interesting to note that a high correlation was found between the ratio and time at every running distance, except the 1320 yard run, which showed a substantially lower correlation. These results suggest that a higher anaerobic capacity in relation to aerobic capacity would result in better times in running. However, these results may be due to the relationship found between anaerobic capacities and aerobic capacities.

This study has shown a linear relationship exists between (1) anaerobic work (kpm) and running time (2) anaerobic capacity and time in running. The correlation between anaerobic work (kpm) and running time increased as the distance increased, and a similar relationship was found between anaerobic capacity and time in running.

These results seem to conflict with those reported by others. Londeree (36) reported that sprinting the races of short duration needed a larger anaerobic reserve (maximal oxygen debt) than the longer distances. Cunningham and Faulkner (15) also reported that runs of shorter distances stressed the anaerobic mechanism. Wilt (21) suggested that in terms of the total oxygen requirement, the shorter distances comprised the largest percentage of total oxygen demands (through oxygen debt). In view of this reported data, Dainty concluded that the proposed anaerobic capacity test which he had evaluated was probably not satisfactory in its present form. This does not rule out the possibility that further refinement of procedures and methods may produce a more easily administered test of anaerobic capacity.

VIII. SUGGESTIONS

It is evident that performance in running is a very complex phenomena. We know that successful performance depends upon a combination of factors which must be present in performances of excellence. This study has suggested that the processes that we call aerobic and anaerobic metabolism play a major role in the total performance of an individual. It has also suggested that it is the efficiency and interrelationship of these two energy yielding processes during exercise which determines, to a great extent, the relative success or failure in running performance. Perhaps, in the not too far future, training methods may be so sophisticated as to include a periodic analysis of an individuals aerobic and anaerobic capacities, and an appraisal of an individual's potential and capabilities may possibly be determined by these processes. This may serve to facilitate a higher optimal performance in competitive running and could also shed light on the kind of training procedures applicable to the general population.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

I. SUMMARY OF PROCEDURE

A pilot study was conducted over a period of three weeks to provide the subjects with ample training for the maximal oxygen consumption test.

For the maximal oxygen consumption test, a warm up was given prior to each testing session. The Sjostrand Test was administered as the warm up and also to determine the PWC-170 for each subject. After the warm up was completed, the maximal oxygen consumption test was administered. At the end of two minutes, gas samples were taken for one minute and analysis was completed. The maximal oxygen consumption was taken as that value which turned down with increasing load, or the value which showed less than 150 milliliter increment.

The anaerobic capacity test is under development by Dainty. A pilot test was conducted over a two week period. The objective was to determine the rate and load which best tested each subject's capacity for anaerobic work. Once found, the anaerobic test was administered. This consisted of working at the highest rate and load combination possible while holding the breath. When the subject could go no longer, the test was terminated and recovery gas sample collected (seven minutes). A sample was then taken and analyzed, giving an oxygen debt value. The amount of work (kpm) was also calculated for each subject.

The performance tests selected were the 330, 660, 880, 1320 and mile run. For the 330, 660, and 1320 yard runs, the subjects were asked to report to the track at the regular work out time of 3:30 p.m. The lanes were assigned randomly and each test run was administered exactly as a track meet. Six officials timed each trial and reported their findings at the end of each trial.

In the 880 and mile run, data was taken as the best times recorded during the competitive year.

II. SUMMARY OF FINDINGS

The findings of this study are summarized in the following statements:

1. A relatively large range of aerobic capacity (49.42 to 64.9 ml/kg/min) was found for the subjects in the study.
2. A relatively large range of anaerobic capacity values (7.81 to 12.91 ml/kg/min) was found for the subjects in the study.
3. A very high correlation was found between aerobic capacity and physical working capacity of the subjects.

4. As the distance increased, the correlation between anaerobic work (kpm/kg) and performance increased.
5. As the distance increased, the correlation between aerobic capacity and performance increased.
6. As the distance increased, the correlation between physical working capacity and performance increased.
7. A fairly high correlation existed between aerobic/anaerobic ratio (composite) and performance in every distance, except the 1320 yard run.
8. The anaerobic data found in this study cast some doubt on the reliability and validity of the anaerobic test under development by Dainty.

III. CONCLUSIONS

The following conclusions may justifiably be based on the findings of this study.

1. There appears to be a significant, linear relationship between aerobic capacity and performance in running. Furthermore, the relationship increases as the distance increases.
2. The anaerobic capacity test using maximal oxygen debt was probably not a satisfactory test in its

present form.

3. There appears to be a significant, linear relationship between the physical working capacity (PWC-170) and performance in running. Furthermore, the relationship increases as the distance increases.
4. There is a highly significant relationship between physical working capacity (PWC-170) and aerobic capacity.

IV. RECOMMENDATIONS

1. It would be interesting to perform a similar study using a larger number of subjects.
2. Continued efforts to devise a valid, reliable and easily administered test of anaerobic capacity would seem valuable.
3. The possibility of defining the functional interrelationships between aerobic and anaerobic capacities and speed should prove to be an interesting line of investigation.
4. It would be of interest to try and relate the psychological effect of pain to the accumulation of lactic acid, the oxygen debt and anaerobic capacity during running.
5. A similar study using a larger sample and partial correlation method to remove the effects of maximal

oxygen consumption, anaerobic capacity or speed should prove to be an interesting investigation.

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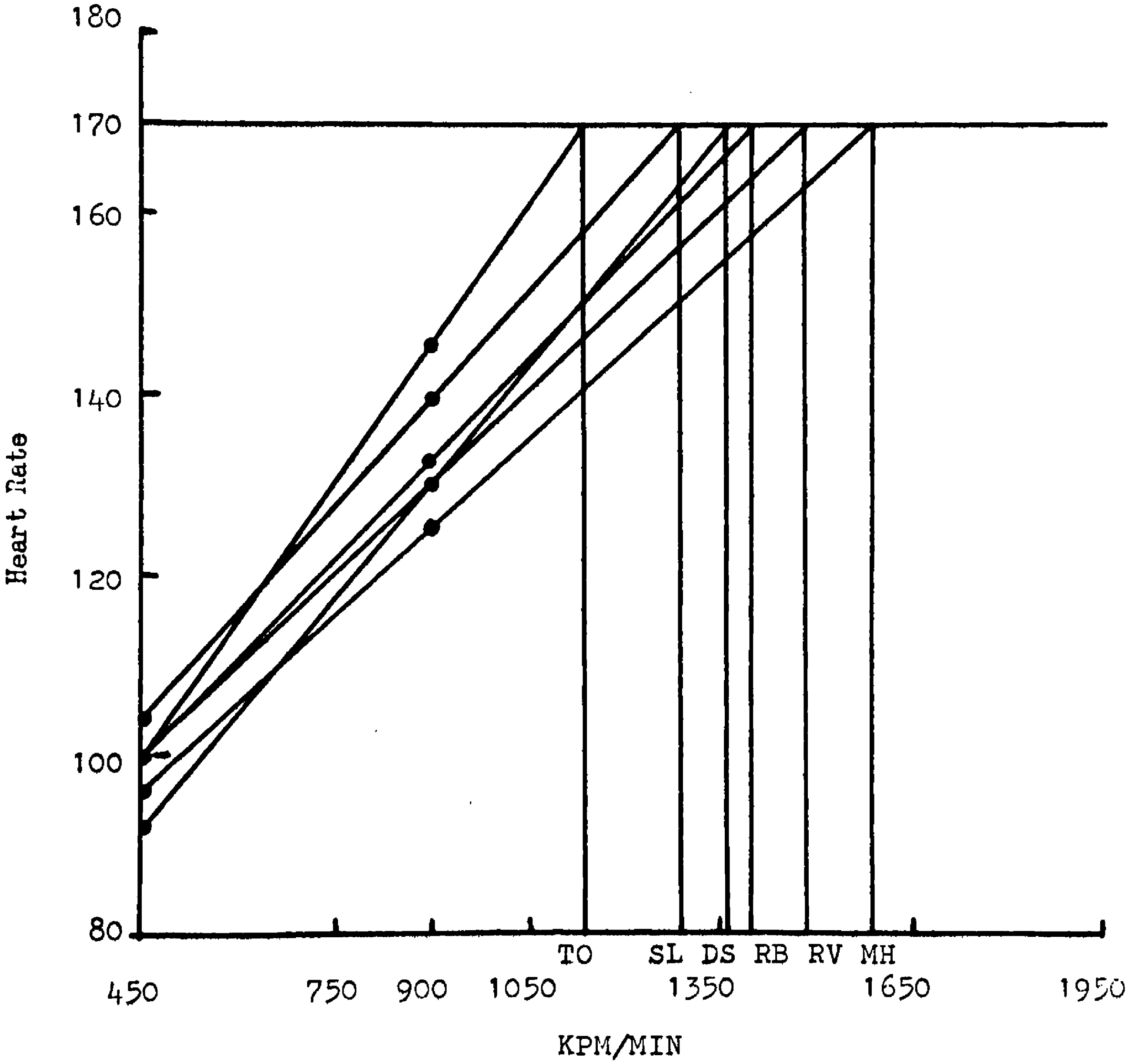
APPENDIX A

PWC-170 TEST



PWC-170 (PHYSICAL WORKING CAPACITY) OF THE SUBJECTS

Figure 18

APPENDIX B

MAXIMAL OXYGEN CONSUMPTION GAS ANALYSIS

TABLE VI

MAXIMAL OXYGEN CONSUMPTION GAS ANALYSIS

	Subjects	Barometric Pressure(mm)	Temp Gas C°	CO_2%	O_2%	Ventilation Rate(lit/min)	Oxygen Lit/min	Oxygen ml/kg/min
	M.H.	684	21°	4.35	16.55	73.60	3.24	50.53
	R.V.	684	21.5°	4.25	16.60	71.30	3.12	54.26
Test 1	R.B.	681	20°	5.40	15.50	71.51	3.91	52.46
	S.l.	684	21°	4.35	16.45	73.60	3.33	54.63
	D.S.	684	22°	3.65	17.25	105.39	3.89	48.74
	T.O.	681	23.5°	4.45	16.70	79.72	3.32	49.42
	M.H.*	684	21°	4.20	16.80	101.84	4.10	64.09
	R.V.*	684	21.5°	3.40	17.50	106.32	3.66	63.86
Test 2	R.B.	681	20°	4.25	16.85	115.51	4.66	62.59
	S.L.	684	21°	3.95	16.80	89.24	3.73	61.25
	D.S.	684	22°	3.15	17.70	137.85	4.48	56.00
	T.O.	681	23.5°	3.50	17.60	101.80	3.32	49.43
	M.H.*	684	21.5°	3.85	17.05	93.76	3.79	59.19
	R.V.*	684	22.5°	3.25	17.60	109.14	3.65	63.83
Test 3	R.B.	681	20°	3.75	17.15	115.93	4.40	59.09
	S.L.	684	21°	3.82	17.00	93.05	3.68	60.50
	D.S.	684	22°	3.60	17.10	113.39	4.45	53.70
	T.O.	681	23.5°	3.35	17.75	102.14	3.21	47.83

*30 second samples taken.

APPENDIX C

ANAEROBIC CAPACITY AND GAS ANALYSIS

TABLE VII

ANAEROBIC WORK ON BICYCLE ERGOMETER

Subjects	Pedal Rate	Ergometer Load	KPM	TBH Time	KPM/kg
M.H.	80	4.5	1467	40.5	23.22
R.V.	90	4.0	1206	33.3	21.22
R.B.	80	4.5	1467	40.5	18.31
S.L.	80	4.5	1463	40.4	20.37
D.S.	80	4.5	1641	45.3	17.71
T.O.	80	4.5	13.75	38.0	20.15

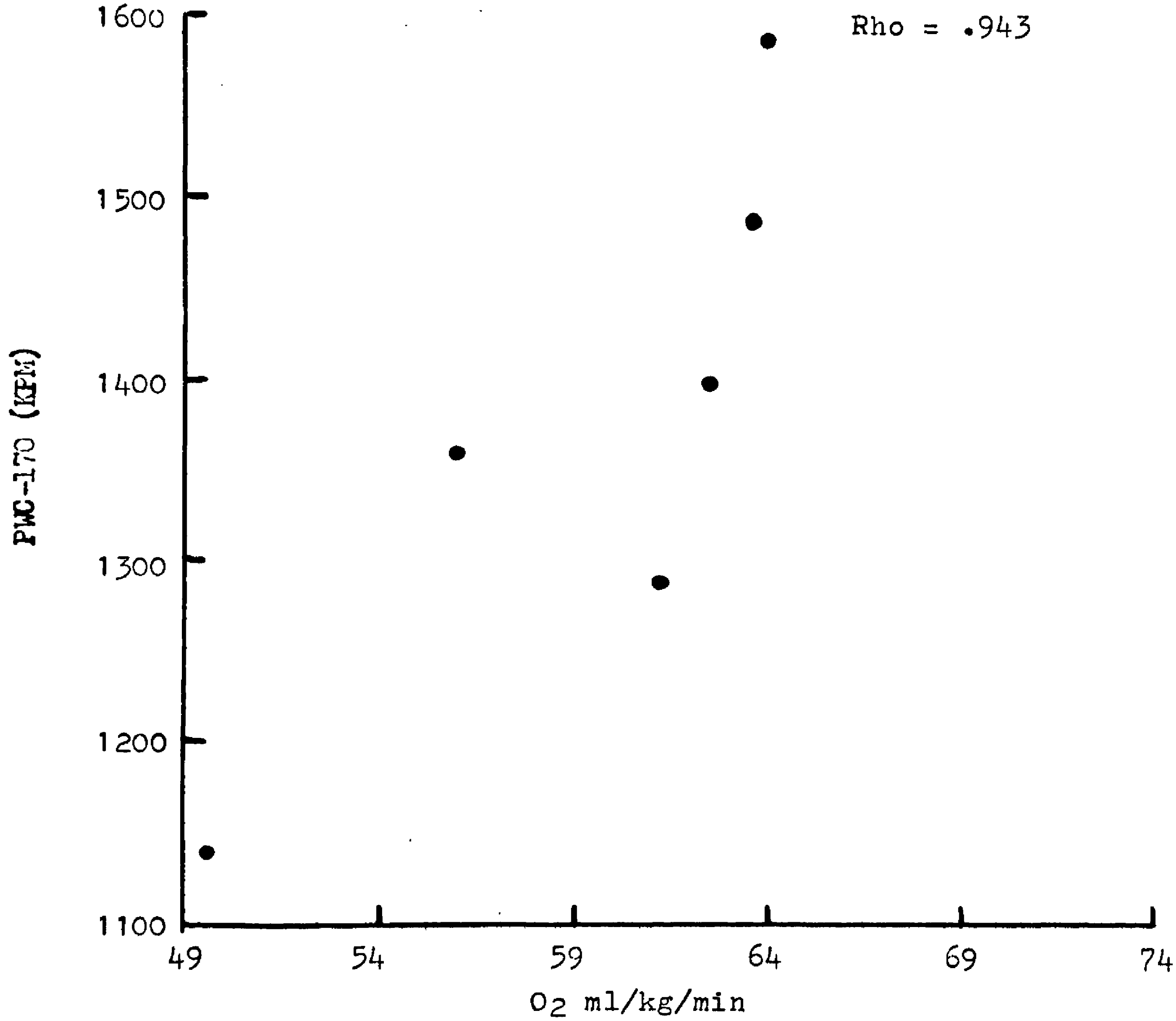
TABLE VIII

ANAEROBIC GAS ANALYSIS

Subj.	Bar. Press.	Temp Gas C°	Vent Rate	O_2 Debt ml O_2/min	O_2 Debt ml/kg/min	O_2 Debt lit/min
M.H.	676	26°	27.63	815.50	12.91	.815
R.V.	676	26°	23.56	706.92	12.44	.706
R.B.	683	22°	21.07	684.93	9.54	.684
S.L.	678	21°	16.80	479.00	7.81	.479
D.S.	677	21°	24.65	665.47	8.51	.665
T.O.	678	21°	18.17	559.67	8.85	.599

APPENDIX D

OTHER PERTINENT RELATIONSHIPS



Relationship between Aerobic Capacity and PWC-170

Figure 19

RELATIONSHIP BETWEEN PWC-170 AND PERFORMANCE

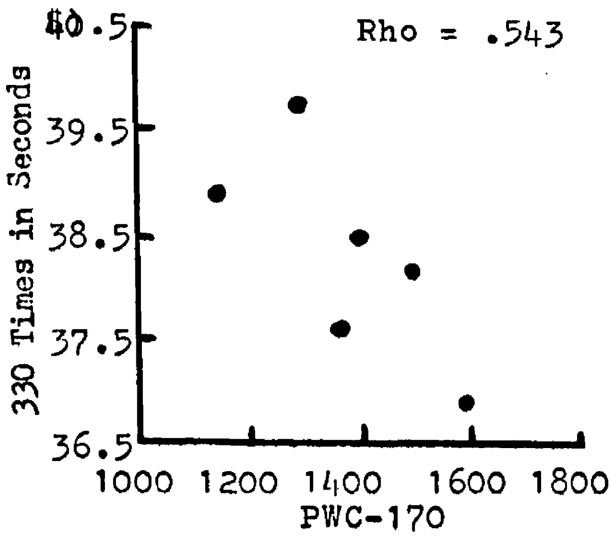
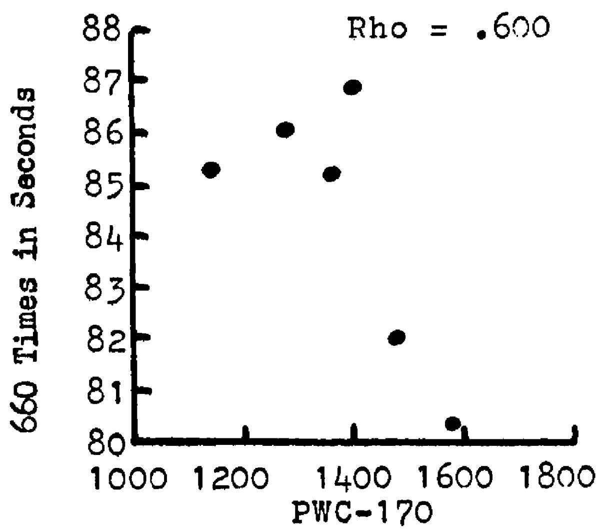


Figure 20



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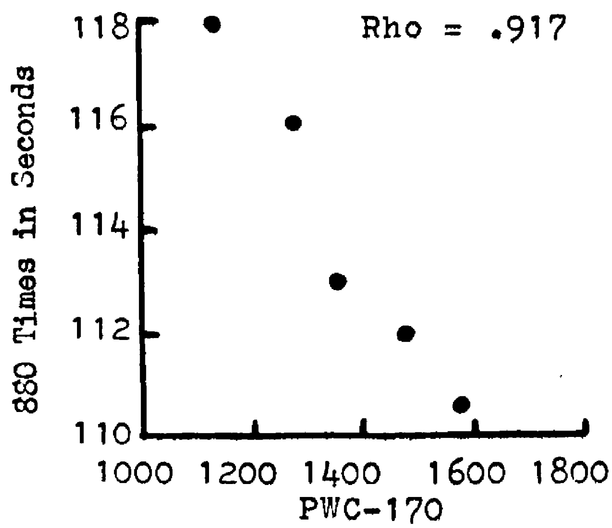

Figure 22

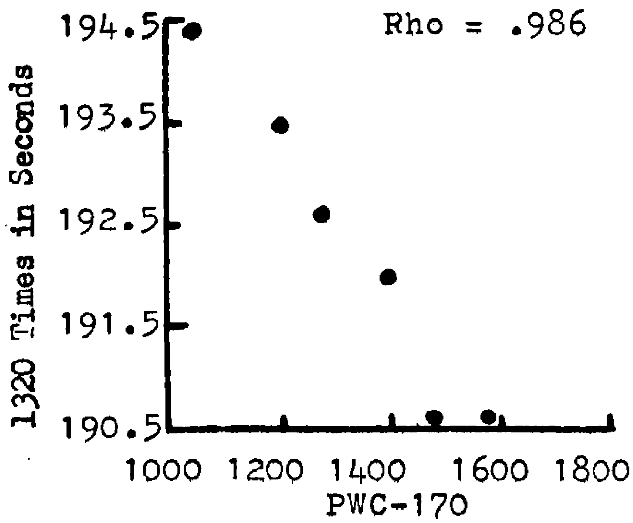

Figure 23

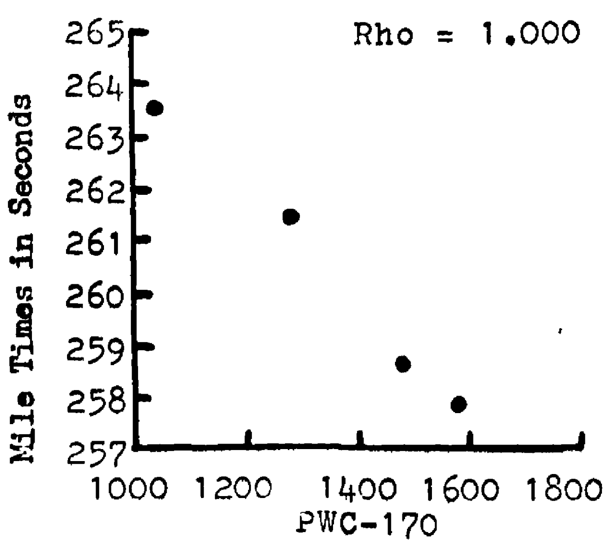

Figure 24

RELATIONSHIP BETWEEN ANAEROBIC KPM/KG AND PERFORMANCE

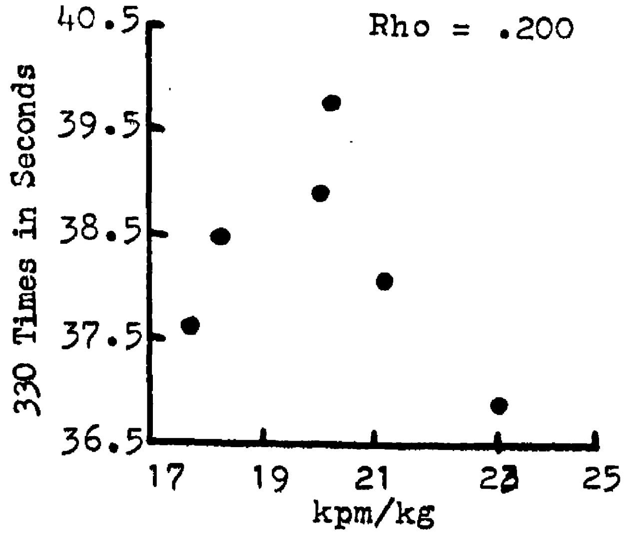

Figure 25

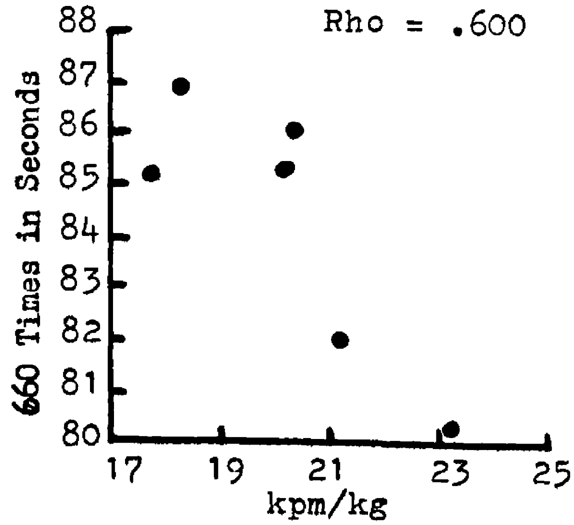

Figure 26

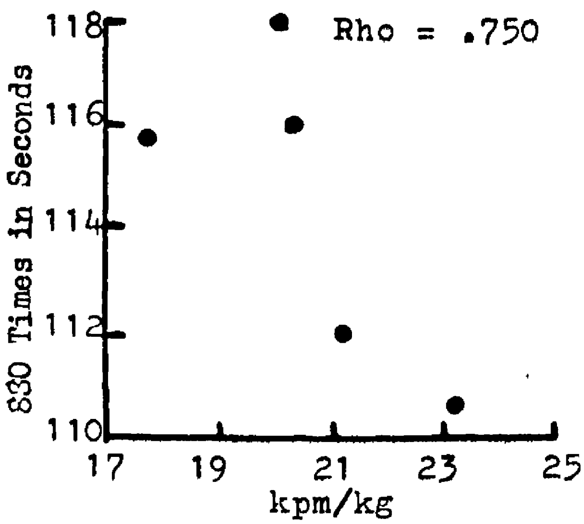

Figure 27

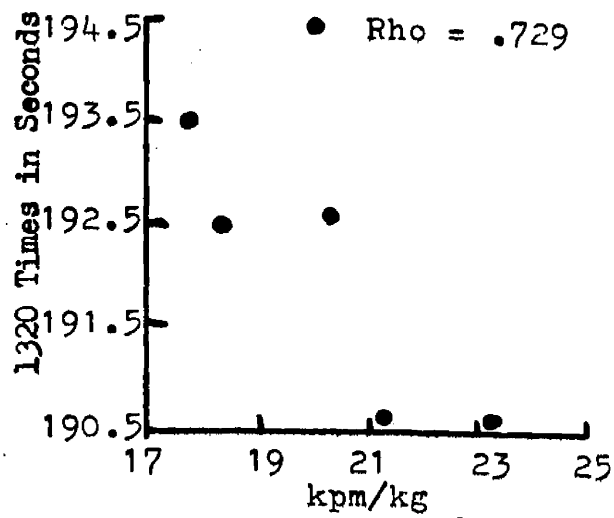

Figure 28

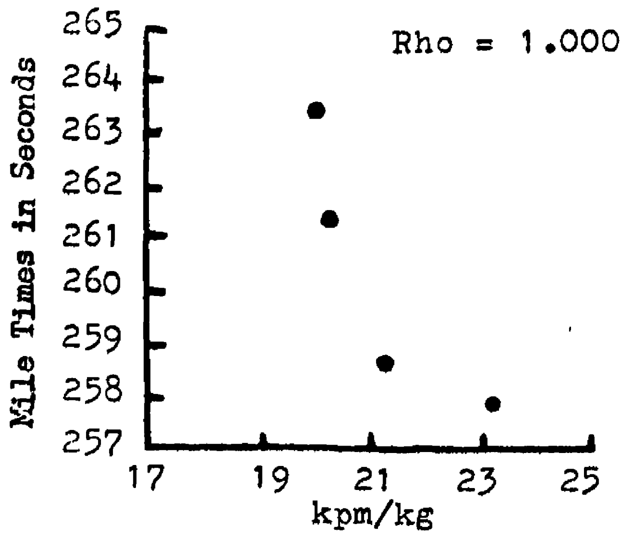

Figure 29

APPENDIX E

STATISTICAL ANALYSIS

STATISTICAL ANALYSIS USED IN THE STUDY

I Formula for Computing Correlation

Spearman-Rho Rank-Order Correlation

$$\text{Rho} = 1 - \frac{6\Sigma D^2}{N(N^2-1)}$$