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The relationship of anaerobic capacity to selected performance tests

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THE RELATIONSHIP OF ANAEROBIC CAPACITY TO SELECTED PERFORMANCE TESTS

BY

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CHAPTER I

INTRODUCTION

In muscular contractions of any intensity, there is a series of metabolic processes which occurs in order to supply the energy for the contraction. There are two parts to this metabolic series, one being aerobic (or the part being performed in the presence of oxygen), and the other anaerobic (or the part being performed in the absence of oxygen). Because there are chemical processes taking place, there is a limit as to how long the system may perform. This limit is imposed upon the system by many factors all of which are not chemical. The supply of metabolic substrates will of course limit the chemical processes, but there is also a limitation in the ability of the individual performing the muscular contraction to dispose of or tolerate the waste products of the chemical reaction, and also the limitation imposed by individual differences in motivation to perform the muscular contraction.

Another way of expressing limitations is to define the total capacity of the system. From the preceding discussion one may see that the capacity may be divided into two parts, the aerobic portion or capacity and the anaerobic capacity. This study was primarily concerned with investigating the latter, how to measure it, and the effect of training upon it.

Anaerobic capacity has eluded definition, quantification, and measurement in human performance. Margaria (29) has contributed to the study of anaerobic power, the measure of the capacity in a unit of time. Margaria states that it may be possible to test the anaerobic power of a performance and then convert this to capacity by multiplying the power (measured in kilogram-metres per kilogram second) by the time during which the exercise was performed. This will give an approximate measure of the anaerobic capacity in kilogram-metres per kilogram of body weight.

Much of the work performed by Margaria has been concerned with the measurement of maximal anaerobic power in man. He states (29) that there are three mechanisms for energy release in muscular activity; the first being the split of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) plus inorganic phosphate and energy to perform the work ($ATP \longrightarrow ADP+P_1$ + Energy). This process is performed without oxygen and thus the most immediate process in muscular contraction is ANAEROBIC. This process releases 10 to 12 kilocalories of energy per one gram molecule (MOLE) of ATP. The initial exergonic process lasts for approximately four to five seconds. Thus Margaria deduces (28) that this is a measure or expression of anaerobic power. The anaerobic power of the body is derived partly from the high energy bonding of ATP and creatine phosphate (CP), (29). Creatine phosphate is also known as phosphagen (PG), but Margaria uses it in the sense that PG = ATP + CP. Therefore, one can resynthesize ATP anaerobically with an end product of PG. This PG is resynthesized aerobically to ATP and CP in the post-exercise state. The oxygen required for this process is known as the ALACTACID FRACTION of the oxygen debt.

From this point, the exergonic processes are aerobic until a point is reached at which anaerobic metabolism once more takes place. This situation arises when the oxygen being transported by the circulatory system is not sufficient to meet the requirements of the cells. When this occurs in severe exercise, a process called glycolysis occurs in which three moles of ATP are produced. The end product of this process is lactic acid (LA), and the oxygen required to resynthesize glycogen from LA after exercise is called the LACTACID FRACTION of the oxygen debt (27). In his studies, Margaria has measured the amount of LA in the blood, and also the pyruvic acid present in order to measure both the lactacid and alactacid fractions respectively. Many problems have arisen in these attempts to measure the metabolic fractions. Huckabee (19) states that there is no such thing as an alactacid fraction of the oxygen debt, and that virtually the entire debt could be accounted for at all levels of work by lactic acid, specifically excess lactate. Most physiologists, according to DeVries (8), disagree with Huckabee and accept Margaria's hypothesis of a two part oxygen debt. Other researchers also indicate that the excess lactate may be taken up by organs such as the heart, liver and kidneys, thus a blood sample will not give a true indication of the total amount of lactate produced in anaerobic metabolism. The preceding discussion suggests the need for another approach to the problem of measuring anaerobic capacity.

If the aerobic portion of the energy producing process is eliminated, an exercise which is almost completely anaerobic may be obtained. This may be attempted by having the subject hold his breath during the exercise so that no oxygen may be breathed in by the subject. From this, one may obtain the alactacid and lactacid fractions of the oxygen debt. By measuring the oxygen debt immediately after the exercise, one should be able to obtain a measure which will be an indication of the anaerobic power (29). One could then convert this to capacity by multiplying the result by the time taken to perform the exercise. This process is obviously quite involved and not as accurate as might be desired. Thus it is suggested that a direct reading of the amount of work performed be used as an indication of the anaerobic capacity. This type of test would make the process of obtaining the capacity much simpler and much more practical to the coach and physical educator, because anaerobic metabolism plays an important role in vigorous physical activity. With the aid of a test that indicates the anaerobic capacity, it may be possible, in association with other tests (eg. aerobic capacity (35)) to predict the best performers in various activities such as swimming and track events. The use of this type of test along with others may also indicate to a coach or the athlete concerned where he may need to concentrate his training efforts.

With a test for the measurement of anaerobic capacity, the question of the effects of training on the capacity then arises. Brouha (2) stated that training improves the anaerobic power as well as the aerobic. In another study, however, Margaria (29) found that running at top speed does not appear to involve a much higher energy requirement than running at a speed not involving an oxygen debt. These findings have led him to believe that training in athletics does not lead to sufficient improvement in anaerobic exercises. Therefore, he feels that training will not significantly alter the anaerobic power of man. In an unpublished thesis, Grunwald (15) trained subjects on short distance runs and found the same results as Margaria. In a very recent study, however, Cunningham and Faulkner (7) indicate that there is a slight increase in anaerobic power after a six week training programme.

In their study, they used a longer run than had previously been used and which seemed to involve anaerobic metabolism more than aerobic. In this study, the author used a shorter run than that used by Cunningham and Faulkner, but of such a distance that the anaerobic capacity or power might be extended and hopefully improved.

I. THE PROBLEM

The problem of this investigation was that of developing a valid test for the measurement of anaerobic capacity in humans. Of specific concern was the development of a test which would not only be both valid and reliable, but also of practical value to the coach and physical educator.

As a sub problem the study also investigated the effects of two different programmes of training on the anaerobic capacity.

II. PURPOSE OF THE STUDY

This study attempted to determine a valid and reliable test of anaerobic capacity. To determine test validity, the test was related to other measures of anaerobic power already being used (5, 6, 29). An additional purpose of the study was to investigate the effects of two different training programmes on the anaerobic capacity.

It was hoped that this study would lead to the development of a test to determine the anaerobic capacity and would be useful in the development of increased overall working capacities, and ultimately, improvements in performance.

III. LIMITATIONS OF THE STUDY

A. The number of subjects was limited to six conditioned middle distance runners, and seven non-athletes chosen from a weight training class at the University of Montana. As the subjects were not chosen randomly the results of this investigation may only relate to these subjects, and any conclusions projected toward the general population will be purely speculative.

B. Numerous extraneous variables such as living habits, personality makeup and individual psychological and physiological limits may have influenced the results of this study.

IV. DEFINITIONS

The following terms are defined as they were used in this study.

Anaerobic Capacity. The total energy available during muscular work without the use of oxygen for metabolic purposes.

Anaerobic Power. The energy produced per unit time in exercise not utilizing oxygen for metabolic processes.

Aerobic Capacity. The total amount of energy available during muscular work utilizing oxygen. It is usually expressed in litres of oxygen per minute or milliliters per kilogram of body weight per minute (35).

Lactacid Fraction. The portion of the oxygen debt which is required to resynthesize glycogen from lactic acid in the post-exercise state.

Alactacid Fraction. The portion of the oxygen debt required to resynthesize adenosine triphosphate and creatine phosphate from phosphagen and pyruvic acid in the post-exercise state.

Oxygen Debt. A term coined by A. V. Hill (8) to describe the oxygen, above the resting level, required to oxidize the metabolic by-products of anaerobic muscular activity in the post-exercise state.

CHAPTER II

SURVEY OF RELATED LITERATURE

I. ANAEROBIC METABOLISM

Before attempting to develop a test for measuring the capacity of an individual for performing work under anaerobic conditions, it is essential that the mechanism of anaerobic metabolism be understood.

In the human organism, the energy needed for muscular exercise is derived from oxidation of carbohydrates and fats (aerobic processes) and from the splitting of glycogen and energy rich phosphates in the muscle cells (anaerobic processes). During prolonged exercise (ten minutes or more) aerobic processes play the most important role, while during short exhaustive work periods (up to one to two minutes), the energy needed is derived mostly from anaerobic processes (18).

The concept of performing work anaerobically, or without the use of oxygen, is not a new concept in the field of exercise physiology. Hermansen points out the study of Fletcher and Hopkins in 1907 (18), who initially detailed the breakdown of glycogen to lactic acid for energy under anaerobic conditions. In their classic study in 1933, Margaria, Edwards, and Dill (24) quote A. V. Hill who in 1924 had hypothesized:

> The oxygen debt is due to the delayed oxidation of a fraction of the lactic acid produced during the anaerobic process of muscular activity.

Two years prior to this study, Lundsgaard (24) demonstrated the partial resynthesis of the phosphocreatine in the presence of oxygen and in the absence of any lactic acid formation or removal. Thus Margaria *et al.* believed that there was more than one part to the oxygen debt. In their study (24), they performed a series of tests to determine the different portions of the oxygen debt contracted. They concluded that there was no extra lactic acid appearing in the blood up to a rate of work corresponding to about two-thirds of the maximum metabolic rate, after which the lactic acid increased very rapidly, with an increment of seven grams for every one litre of oxygen debt contracted. The removal of lactic acid from the body was a very slow process. From these two statements, it follows that the lactic acid mechanism would not play an important part in muscular contraction except in very strenuous exercise, probably in connection with anaerobic conditions. The investigators also found that there were four parts to the oxygen consumption curve during recovery, two of which contribute to the oxygen debt payment, the lactic acid and alactic mechanism. The other two parts are attributable to the basal oxygen consumption and the decrease in oxygen consumption during recovery, which lasts for several hours after exercise.

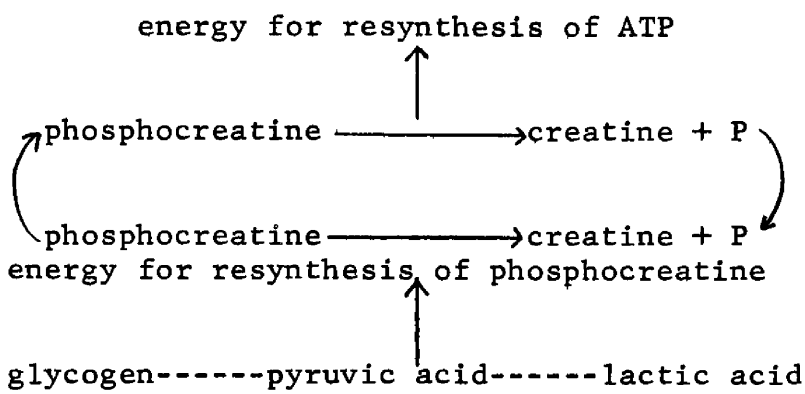
In another paper in 1934, Margaria and Edwards (25) expanded on the hypothesis of a two part oxygen debt. They found that the increase in the concentration of lactic acid in the blood following muscular work performed under anaerobic conditions is a linear function of the amount of work (L. A. = -a + bW) and the amount of work performed anaerobically may be considered to be proportional to the oxygen debt (L. A. = $-a' + b'O_d$) (25). The fact that the relationship is linear suggests that the breakdown of glycogen into lactic acid is really one of the mechanisms for contracting an oxygen debt, and therefore for performing work anaerobically The fact that the constant "a" is negative supports the hypothesis of the existence of a second mechanism for performing work anaerobically.

Huckabee suggests that all instances of lactate production can be divided into three types: lactate produced due to (1) inadequacy of oxygen supply relative to metabolic needs, (2) change in pyruvate production alone, and (3) changes in both factors simultaneously (19). He indicates that for practical purposes 1 does not seem to occur and, therefore, it becomes important to distinguish lactate changes due to 2 from those due to 3. Huckabee hypothesized that there was not in fact a lactacid and alactacid portion of the oxygen debt.

In a study conducted on two non-athletes and one athlete in which the subjects were run to exhaustion on the treadmill, Margaria _et al._ (27) disproved the hypothesis advanced by Huckabee. They found that excess lactate did not disappear with the same kinetics as oxygen debt payment after exercise, in the first five to eight minutes, while oxygen consumption in that time had nearly reached the pre-exercise levels. The lactic acid process is a delayed process, and an exergonic process which is not lactic acid formation, must take place at the beginning of exercise. This is the contraction of the alactacid oxygen debt.

The hypothesis that there are two parts to the oxygen debt following exhaustive exercise is now supported by most exercise physiologists (7, 8, 11, 18, 29). The actual chemical reactions of anaerobic metabolism which comprise the two phases of oxygen debt contraction are based on the process called glycolysis. This has been termed the anaerobic or glycolytic portion of the muscle cell metabolism (7).

The splitting of ATP anticipates all other exergonic processes; therefore, the most immediate process in muscular contraction is anaerobic (29), with the resynthesis of ATP usually being aerobic. Thus there seems to be a lack of oxygen in the initial period of muscular work. This delay in respiratory uptake of oxygen could be caused by the relatively sluggish response of the circulatory system (18). In emergency situations, such as involving severe, short term exercise, the process of glycolysis also takes place. This reaction is simplified by deVries (8) and explained by means of the following chart:



The breakdown of glycogen to glucose occurs initially in the sarcoplasmic portion of the muscle. This process can proceed without consumption of oxygen and is the anaerobic or glycolytic portion of the metabolism (13). Degradation of glycogen and glucose to pyruvate porduces a net gain of two and three ATP's respectively. The critical step in this pathway is reached with the formation of pyruvate. At this point, if oxygen is available, pyruvate is converted to acetyl CoA and oxidized to carbon dioxide and water by way of the Kreb's cycle (11) and the electron transport system (13). In the absence of oxygen, pyruvate is reduced to lactate by the lactate dehydrogenase system (LDH) and diffuses into the blood.

The glycogen is readily available in muscle tissue because it is stored for the most part in the sarcoplasmic spaces. Glycogen is also stored in the liver and is released during exercise into the blood in the form of glucose. This is brought about by the enzyme phosphorylase, which acts as a catalyst in the breakdown of glycogen to glucose-1-phosphate. In muscle, this glucose-1-phosphate is further metabolized by way of glycolysis, the Kreb's cycle, and the electron transport system to produce carbon dioxide, water and ATP. In the liver, the glucose-1-phosphate is converted to glucose-6-phosphate and then may either be metabolized or cleaved to free glucose and phosphate by the enzyme glucose-6-phosphatase. The free glucose then can be released from the cell into the blood. Muscle does not possess the enzyme glucose-6-phosphatase and thus cannot release the glucose from glycogen back into the circulatory system. Therefore, the glycogen reserves of non-working muscles cannot be transferred to the working muscles (13). Thus a limiting factor is encountered in anaerobic metabolism.

At this point, one may again consider the role of the first exergonic process in muscular contraction. This initial energy source is the breakdown of ATP. It is very difficult to measure this breakdown because of the fast regeneration of ATP from phosphocreatine (PC) with the aid of the catalyst enzyme phosphoryltransferase (CPT). This regeneration is brought about by combining PC with ADP in the presence of CPT to obtain ATP and creatine as a by product (3, 13). In this reaction, however, an inorganic phosphate must be present to complete the reaction. This inorganic phosphate (P_i) comes from the breakdown of ATP to ADP and P_i, by way of the enzyme actomysin ATPase (3). By reducing the level of ADP, the breakdown of ATP is facilitated because ADP inhibits actomysin ATPase.

This high energy bonding of ATP and phosphocreatine is partially responsible for the anaerobic power of the body, the other part coming from the incomplete oxidation of glycogen to lactic acid. The resynthesis of the creatine phosphate or phosphagen (although Margaria uses phosphagen in the sense of PG = ATP + PC) is what has been previously termed the alactacid fraction of the oxygen debt. The resynthesis of glycogen from lactic acid is the lactacid fraction. Now both fractions have been defined in terms of their metabolic functions.

As discussed previously, without oxygen the pyruvate will break down into lactic acid. One may see a linear increase of lactic acid in the venous blood. The speed of lactic acid formation in the blood has been measured as a function of the intensity of exercise. There is a linear relationship between the amount of lactic acid produced and the mechanical energy obtained (29). The amount of lactic acid produced in grams per minute is a linear function of the intensity of the exercise (dW/dg). The energy equivalent of lactic acid is 220 kilocalories per gram. Therefore, with this information one is able to find the exact energy balance between aerobic and anaerobic processes (29).

The upper limit is reached in exhaustive exercise in less than forty seconds and amounts to a production of 1.6 grams of lactic acid or 350 kilocalories. This amount is known as the Power of the Lactacid Mechanism (29).

It is interesting to note at this point, that no lactic acid is formed in the first few seconds of even strenuous work. This may be attributed to the fact that the alactacid mechanism is working at this time. The maximum power at this time is forty-five kilocalories per kilogram-hour, and the capacity of the system is 196 kilocalories per kilogram or eleven millimoles of PG per kilogram of body weight. The alactacid oxygen debt should be proportional to the oxygen consumption (29). The oxygen stores measure about 550 millilitres of oxygen during maximum aerobic exercise, as can be measured from the assumptions that (1) venous blood is fifty per cent more desaturated in exercise than at rest, (2) venous blood is eighty per cent of the total blood volume, and (3) myoglobin with a concentration of two grams per kilogram of muscle tissue is completely saturated with oxygen at rest and completely desaturated in maximal exercise. Therefore, the net alactacid oxygen debt is 2.5 minus 0.55 or 1.95 litres, and has a half reaction time of twenty-two seconds (i.e. the time taken to reduce alactacid debt in half). The lactacid debt is much slower with a half reaction time of fifteen minutes (29).

Henry, in a study on thirty-five non-athletes and twenty-three athletes (17) found that the alactacid oxygen debt is probably not just due to the lag of circulation or other adjustment processes in the initial phase of moderate exercise, but is instead a necessary consequence of exercise oxygen consumption being controlled by the production of oxidizable substrate, thus agreeing with what Margaria has said. Henry also found that the magnitude of the oxygen debt estimated from the recovery curves was significantly greater than the oxygen deficiency contracted during the work, suggesting that the alactacid debt oxidation is less efficient than oxidation during exercise.

The efficiency of anaerobic work has also been discussed by Hermansen (18). He found that the energy liberated when lactic acid is produced is about half of that which is necessary to remove the lactic acid. The relationship between the oxygen deficit (the lack of oxygen in the initial period of work before the steady state is reached) and the oxygen debt, constitutes one method of determining the efficiency of anaerobic work. He reports that Asmussen found the oxygen deficit to be forty-three per cent of the oxygen debt, which agreed with what other researchers had found. He concludes that when work is performed in an almost completely anaerobic condition, the oxygen debt is about twice the size of the oxygen deficit.

The limiting factors in anaerobic work are not well researched. As mentioned in the previous discussion, the supply of glycogen along with other exergonic materials will limit the exercise. The main limiting factor, which does depend on the other factors, is the speed of ATP production in view of the very limited store of ATP in the muscle cells at the beginning of exercise.

Other authors (18) have tried to attribute the limitation to other factors, such as lactate in the blood, the pH of the blood, the intracellular pH, the inability to release energy anaerobically after thermal dehydration. All of these theories remain speculative at this time. Knuttgen (21) also mentions the role of psychological limitations not only in anaerobic work, but in any form of exercise.

II. TESTS

The limitations of the anaerobic system will of course place a ceiling on the amount of work that can be produced under anaerobic conditions. This ceiling may be termed the capacity of the system. Many studies have been concerned with finding the aerobic capacity in muscular work. One such study was undertaken in conjunction with this investigation. Stagg (35) has found the aerobic capacities of the athletes used in both experiments, and has found a high relationship between aerobic capacity and performance capacity. Other authors (18) have also shown large differences in aerobic work capacity between groups with different levels of physical activity. The question of anaerobic capacity has not received as much attention. This is mainly due to the lack of an adequate test, or as Hermansen states:

> The range of variability as far as anaerobic work is concerned has not been determined because there has been no accepted test procedure to measure this capacity.

He states further (18) that;

> The use of oxygen debt as a measurement of anaerobic capacity has been considered of little importance, due to the fact that several factors are believed to affect the resting oxygen uptake, consequently,the oxygen debt.

In spite of this information, oxygen debt has been measured to determine whether the classical concept of oxygen debt could be used to distinguish between groups which are supposed to have different capacities to perform short, exhaustive work.

Margaria has used different techniques in his attempts to define the anaerobic capacity and the anaerobic power. He has attempted to measure the lactic acid produced (24, 25, 26, 27, 28), but many problems have been encountered in this form of measurement. Other physiologists explain that lactic acid is taken up by other organs of the body such as the heart, liver, and the kidneys (8, 11). Thus it would appear that the use of lactic acid as an indication of anaerobic capacity is impractical and possibly invalid.

Margaria has also attempted to measure the oxygen debt in determining the maximum anaerobic power in man. He found (29) that the upper limit of both the oxidative and glycolytic processes determines the maximal power of the two (alactacid and lactacid) energy sources. In the first five to six seconds of work, energy is supplied completely by the phosphagen breakdown and no oxidation or glycolysis takes an appreciable part. Energy expenditure can then be expressed in terms of oxygen consumption instead of mechanical work. The anaerobic power is about three times the maximum aerobic power or in young healthy non-athletes, about forty-eight to fifty kilocalories per kilogram-hour. He also says that on the other hand, lactic acid formation from glycogen is an energy giving process and this is the meaning of the oxygen debt contraction.

In another study Margaria (28) used the oxygen debt measurement and found that the alactacid debt, as measured in man running on the treadmill, seems to be approximately proportionalto the energy expenditure. It amounts to, at most, 0.1 kilocalorie per kilogram or 1.4 litres of oxygen for a man weighing seventy kilograms. The lactacid debt amounts at most to 0.22 kilocalories per kilogram or three litres of oxygen. The alactacid debt contraction is faster, requiring ten to thirty seconds for completion, while the lactacid debt contraction is completed in about forty seconds in the most strenuous exercise. Therefore, at the highest work load, the only energy source available after the first forty seconds resides in the oxidative processes. From this study, Margaria *et al*. have developed a table to show the capacity and power of energetic processes in muscle. The total energy, measured in calories per kilogram was infinite for aerobic processes, ninety-five for alactacid oxygen debt, and 220 for lactacid oxygen debt. The maximum power in kilocalories per kilogram hour was 15.0 for aerobic, 45.0 for alactacid and 21.5 for lactacid, or the opposite order than that evidenced in capacity.

From the preceding studies, it would appear that although there is some discrepancy as to the value of the tests used to date in measuring the anaerobic capacity, even Hermansen agrees that there is some value in measuring the oxygen debt, for it does indicate to some extent the power and capacity of the system. The same is true of the lactic acid measurement but this process is more limited and less widely used.

Margaria, Aghemo, and Rovelli (26) have attempted to measure the muscular power (anaerobic) in man. Because the oxidative reactions in muscle activity as well as the emergency exergonic process of the lactic acid formation from glycogen are delayed processes and certainly do not contribute to an appreciable extent in the first four or five seconds of muscular activity, the power developed in very short exercise may be an indication of the phosphagen splitting mechanism of work alone. Margaria *et al*. found that when a person runs up a staircase at top speed and with maximal effort, a constant speed is reached in one to two seconds which remains constant until the fifth second. This exercise seems to be very convenient because it appears that the energy requirement for speed maintenance in running a given distance is independent of speed. When running at an incline greater than thirty per cent, the external work is given practically by the body lift alone. Therefore, by measuring the vertical component of the speed between the second and fourth second of the run, when a constant speed level is reached, the maximum power is obtained, thus avoiding the calculation of energy employed for the vertical acceleration.

Costill (5, 6) has used a modified stair run test, and has obtained similar results. In the first study (5), he tested the maximum anaerobic power of players at different positions on a college football team. By using the stair run test he found velocities which were slightly lower than those found by Margaria. Costill says this may be due to the weight of the subjects and also the test modifications. He also noted, however, that the caloric consumptions (kilocalories per kilogram hour) were below those found by Margaria. It appears that Costill is in agreement with Margaria that the maximum anaerobic power can be measured by means of a maximal effort stair run test.

In another study (6), Costill found a high correlation (r = .751) between anaerobic power and squat leg lifts. The method of determining the maximum anaerobic power is as described by Margaria (26) and modified by Costill (5). The test utilized each subject's vertical component of speed (maximum velocity generated during the stair run test) and the body weight of the individual to calculate the total power output in foot pounds per second. An assumed work efficiency of 25 per cent is then employed to convert the known work output to an estimated rate of energy utilized (kilocalories per minute). Costill concludes, therefore, that Margaria's test is composed of two measures; vertical velocity and maximum anaerobic power. However, when computed as a function of body weight, the maximum anaerobic power is composed of one component, vertical velocity. Costill found a correlation between vertical velocity and anaerobic power of .172, suggesting that the maximum vertical velocity does not measure the push-off component of the start. Therefore, its major component is speed of leg movement. The high correlation between anaerobic power and squat weight lift is explained in part by the fact that there is a high correlation between squat weight lift and body weight, a factor utilized in computing the anaerobic power (6).

In a recent study, Cunningham and Faulkner (7) used the treadmill as a device for testing the anaerobic power. They used a short exhaustive run with the treadmill set at a grade of twenty per cent. The subject ran without a warm-up at a speed of 7 or 8 miles per hour, depending on his performance on a previous test of maximum oxygen uptake. Because of the type of treadmill available and the danger inherent in such an exhaustive run, the author of the present study felt that this type of test would be impractical.

III. TRAINING

From the preceding discussion one may readily see that the effects of training on the anaerobic capacity would be difficult to determine because of the lack of a clear and definitive test for measuring the capacity. Cunningham and Faulkner (7) say that the amount of energy obtained by anaerobic processes cannot be measured directly. It can be approximated by measuring the amount that the metabolism is increased above resting values following exercise (oxygen debt) and by measuring the difference between resting blood lactate and the highest value observed during or after exercise. Neither oxygen debt nor blood lactate concentration provide a solution to the enigma of a quantitative measure of anaerobic metabolism. However, both can be employed as gross indicators of anaerobic sources of energy and when applied to the same subjects performing on the same test they may be used to assess relative changes in these sources.

With respect to the preceding statement of Cunningham and Faulkner, it may be observed that several authors have indicated that training does have a beneficial effect on the anaerobic capacity. In 1941, Harmon and Robinson (33) discovered that nine subjects increased their ability to accumulate or tolerate lactic acid after a six month training programme. They also found that during grade walking lactic acid declined slightly with training. The training consisted of running short and middle distances four times a week with time trials every Saturday. The shortest distance run was one hundred yards and the longest distance was one mile.

More contemporary studies have indirectly agreed with what Robinson and Harmon said. In a training programme with twenty-two subjects, Londeree and Corrigan (23) found that repeated sprints of 150 and 250 yards will produce a greater training effect for oxygen debt capacity than will longer runs. That is to say that the maximum oxygen debt increased with sprints rather than with longer runs. The difference found was not significant, but there was a difference which indicates that Robinson's shorter runs may have been the cause of the increased ability by the runners to accumulate more lactic acid.

In another study, Hermansen (18) pointed out that measurements on swimmers show that the oxygen debt may be increased during a training period, but he does not specify the type or duration of the training. He also indicates that in studies performed on animals, the stores of ATP and phosphocreatine are increased during training, and also the ability to produce lactic acid is markedly affected by training, increasing from 15.4 to almost 18 millimoles, but falling rapidly upon cessation of training.

The type of training indicated then consists of short runs from twenty to sixty seconds duration. Wilt (37) said that what he has termed fast interval training is a good method of developing anaerobic endurance (endurance in the absence of oxygen, or the general ability to withstand fatigue of the entire organism) as is repetition running. He uses short repetitive runs in his fast interval training. This tends to agree with the other literature cited. In his repetitive running, however, the intervals vary from 880 yards to two miles with sufficient rest between each to allow the heart rate to return to less than 120 beats per minute. Thus there is an apparent contradiction in that longer runs have an effect on the anaerobic endurance. This contradiction may be partially explained by Wilt's definition of anaerobic endurance from which it may be seen that factors other than increased anaerobic power may effect this endurance or ability to withstand fatigue.

In a recent study, Cunningham and Faulkner (7) have shown results which agree with most of the literature cited (18, 37). They tested eight males on a treadmill at eight miles per hour and on a grade of twenty per cent. The subjects participated in a six week training programme of interval sprints of 220 yards and a total distance of two miles per training session. On alternate days the subjects ran for two miles as fast as possible after a one mile warm-up. They reported a twenty-three per cent improvement in running time for the treadmill test after the training period. No change was observed in the oxygen uptake during the first thirty second period of metabolic adjustment. The oxygen uptake during the remainder of the run was higher after the training period. Compared to pre-training results, there was a nine per cent increase in oxygen debt and a seventeen per cent increase in blood lactate concentration. The extra energy needed for the longer post-training test can be attributed to the increased oxygen uptake during the final stages of the run, to increased glycolysis, and to an increased capacity to incur an oxygen debt.

From these studies, one may conclude that training may increase the capacity or power of the anaerobic system. However, it must be remembered that the amount of energy obtained by anaerobic processes is not directly measurable. Furthermore, in training there are processes other than just the physiological systems being affected. One of the other factors involved is the psychological effect training has on the individual. Wilmore (36) suggests that supramaximal performances elicited under experimental conditions result from an increased anaerobic rather than aerobic capacity, probably due to reduced psychological inhibitions and a concomittant tolerance to the increased levels of anaerobic metabolites. Knuttgen (21) has also indicated the importance of the psychological factors involved. He stated that although these psychological factors do not determine the capacities such as physical size, energy release, energy sources, strengths, or skills, they definitely affect the individual's expression and use of these capacities.

IV. SUMMARY

In summary, it can be seen that the definitive measurement of the anaerobic capacity is a very difficult and complicated task. This difficulty arises from the many factors involved in anaerobic metabolism and also the inability to completely separate anaerobic from aerobic metabolism (i.e. to say where one ends and the other begins). The tests which have been developed to date, both physiological (lactate and oxygen debt measurement) and mechanical (stair run and squat weight lift), have not proven to be as valid as might be desired in an investigation of anaerobic capacity. However, it does appear that lactate and oxygen debt measurement do give an indication of the person's ability to work anaerobically and thus have been used as measures in many of the studies concerned with the inquiry into anaerobic power and capacity.

The use of the treadmill as a device for obtaining maximal effort as used by Cunningham and Faulkner (7), appears to be a very dangerous test situation, for the subject is run to exhaustion and then expected to jump off the treadmill. The anxiety attached to running on the treadmill also detracts from its usefulness as a test situation for obtaining maximal effort.

By using the tools of measurement currently available, it appears that training does have an effect on the ability to perform work anaerobically. This training is of a specific sort, however, consisting of short repetitive runs. With respect to the various training studies it appears that the least one can say is that specific training may positively alter the known measurements.

CHAPTER III

METHODS AND PROCEDURES

I. SUBJECTS

The subjects for this study were chosen from two different sets of students at the University of Montana. The initial six subjects were selected from the Varsity Track Team because they were specifically trained middle-distance runners. This group is referred to in this study as the athletes.

The non-athletes, used to determine the effects of training, were chosen from a weight-training class which met during the Spring Quarter at the University of Montana. The eight subjects chosen were divided into two groups. Four of the subjects were in a group which trained by means of a weight lifting programme, and four others were in a group which trained by means of short repetitive runs. However, one subject was dropped from this group when he missed four consecutive training sessions.

Both groups of subjects were given an orientation as to the purpose of the study, the nature of the study, their expected physical behaviour while not involved in testing or training, the procedures they would follow when reporting to the testing and training sessions, and finally, the necessity and value of their cooperation in making the study a success.

The trackmen were very willing to participate, and being highly self-motivated, did not require any extrinsic motivation by the author. The non-athletes were motivated to participate by the promise of top grades in their Physical Education class upon successful completion of the required training and testing programme.

The athletes did not train specifically for the study, but carried on their normal training programme. The non-athletes were randomly placed into the two training groups. There were four subjects in the group training by means of progressive resistance exercises and there were three subjects in the group training by means of short repetitive runs. The physical characteristics of the subjects may be found in Appendix A, while the characteristics by groups are found in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF THE GROUPS

Group	$\bar{X}$ Height in inches	$\bar{X}$ Weight in pounds	$\bar{X}$ Age
Athletes	71.2	146.3	20.3
Non-athletes (weight trainers)	71.0	158.5	18.5
Non-athletes (runners)	71.2	164.7	19.3
MEANS	71.1	156.5	19.4

II. EQUIPMENT AND APPARATUS

Monark Bicycle Ergometer

The anaerobic capacity test was administered on a Monark Bicycle Ergometer located in the Human Performance Laboratory at the University of Montana. This is a stationary bicycle upon which the resistance is varied by manually increasing or decreasing the tension on the friction belt. The ergometer was calibrated prior to testing according to the instructions accompanying the ergometer (1) and found to be accurate. The computation of the various loads used in the test will be discussed in the section on test procedures. The Monark Bicycle Ergometer is illustrated in Figure I.

Gas Collection Apparatus

The equipment used for gas collection was mounted on a portable table for convenience of movement (Figure I).

Collin's Triple-"J" Breathing Valve. The high capacity, low resistance valve is a clear plastic cylinder with inlet and outlet valves made of thin rubber. This valve allows the subject to breathe in room air and exhale into the Douglas Bags.

Hans-Rudolf Four Way Valve. This valve is a metal valve with one inlet and four outlets controlled by a movable circular valve inside the cylinder. The valve allows the operator to direct the subject's exhaled gas into the desired gas collection bag.

Douglas Bags. The 200 litre, rubber-lined, canvas bags were used to collect the subject's expired air. The gas was directed into the bag by means of the Hans-Rudolf Valve through an inlet tube leading into the top of the bag. A smaller tube leads from the inlet tube. Through this tube samples were drawn for subsequent analysis.

One and one-quarter inch corrugated tubing. This tubing was used to make connections between the various pieces of apparatus.

Nose-piece. The nose-piece, a steel clamp with foam rubber padding, was used to seal the subject's nostrils so that he could neither inhale nor exhale through his nose.

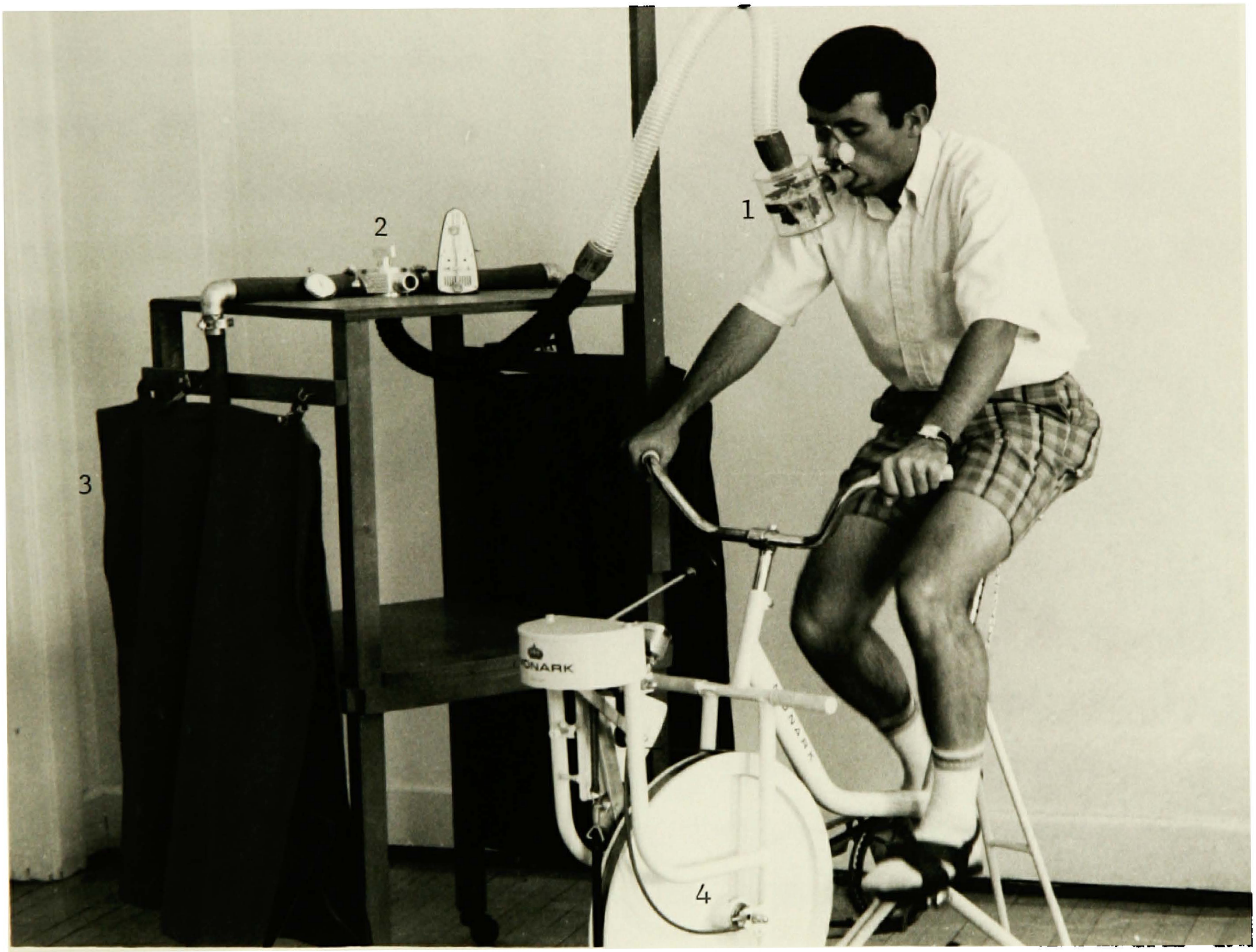


FIGURE I

GAS COLLECTION APPARATUS

1. Collin's Triple-"J" Breathing Valve
2. Hans-Rudolf Four Way Valve
3. Douglas Bags
4. Monark Bicycle Ergometer

Gas Analysis Equipment

The equipment used in analyzing the collected gas is illustrated in Figure II.

Bailey Bottle. The Bailey Bottle consists of two glass cylinders joined to one another in the base to allow mercury to balance. A valve allowed the gas samples to be collected and stored by means of a mercury and glass seal.

Chain Compensated Gasometer. This 600 liter gasometer consists of a cylinder within a cylinder. The inner cylinder was caused to rise and thus vacuum the air from the Douglas Bags. The volume was then read from the scale on the side of the gasometer. A centigrade thermometer, attached to the top of the gasometer with a range from 0° to 40° centigrade, was used to determine the temperature of the sample gas.

Fisher-Hamilton Gas Partitioner. Sample gases were introduced via an inlet port into a 0.25 milliliter sample loop. From this point a continuous 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 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

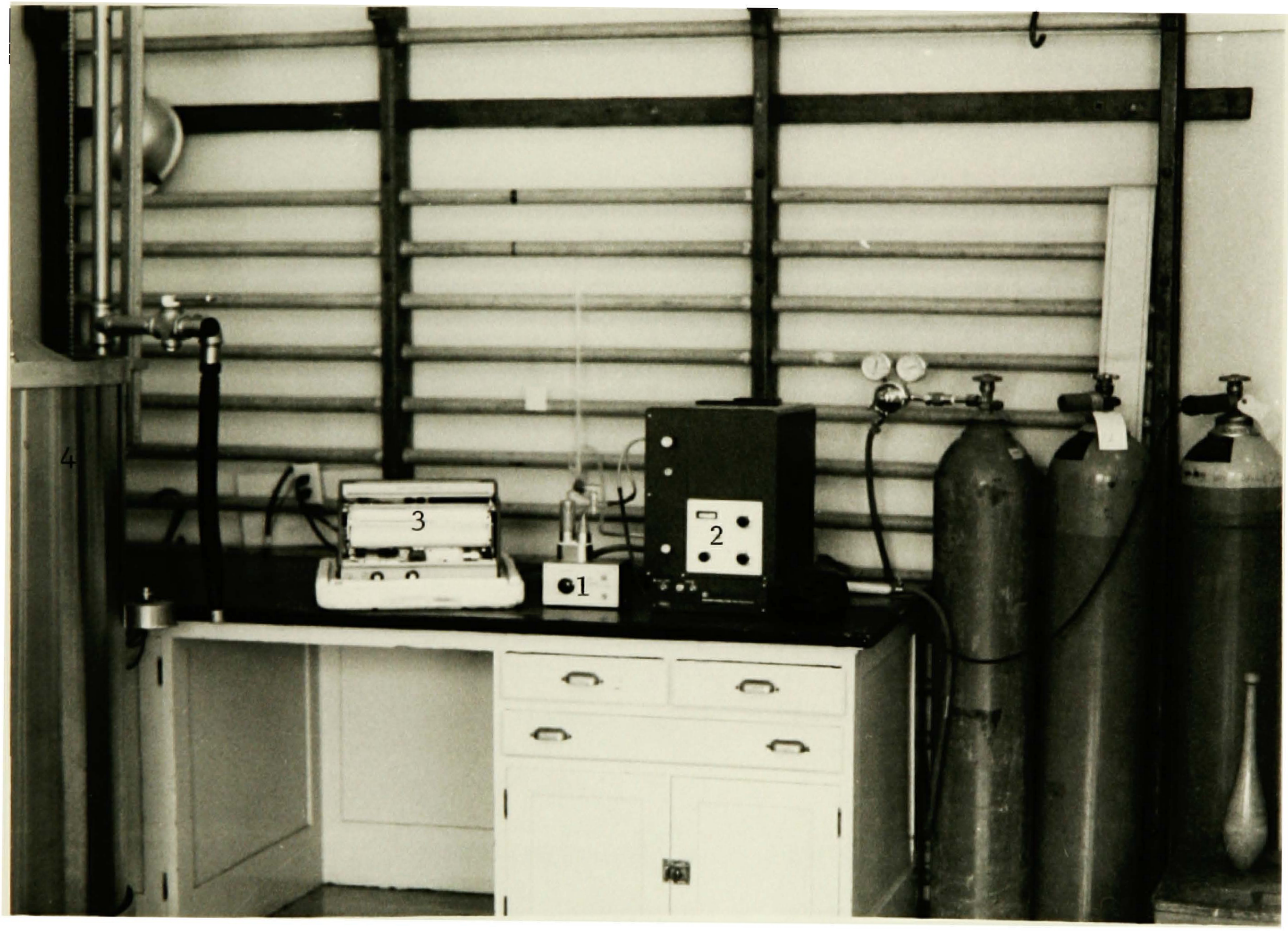


FIGURE II

GAS ANALYSIS EQUIPMENT

1. Bailey Bottle
2. Fisher Hamilton Gas Partitioner
3. Servo-Riter II Recorder
4. Chain Compensated Wet Gasometer

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 in a later section.

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 is 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 2.24 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.

Timing Equipment

The equipment used in this study for timing the various tests is illustrated in Figure III.

FIGURE III

TIMING EQUIPMENT

1. Automatic Performance Analyzer (Dekan timing device)

2. Stop Watch

3. Metronome

Dekan Timing Device. This device also known as the Automatic Performance Analyzer is a timing device capable of measuring to the nearest one-hundredth of a second. It was used to time the stair run test. The timer is started and stopped by means of special accessories which connect to the recorder by means of jacks. The two accessories used in this study were the on-off switch connected to the special start control, and a mat switch connected to the special stop control. The analyzer works on 110 volt AC electricity. The clock is started by means of a clutch assembly so that no inertial lag occurs when the timer begins.

Stop Watches. The stop watches used were sweep hand thirty second watches which timed to the nearest tenth of a second. They were used to time the length of the ride on the bicycle ergometer and also the time required to collect the recovery gas.

Other Equipment

Barometer. An anaeroid barometer was used to measure the atmospheric pressure during each gas collection test.

Thermometer. A mercury thermometer was used to record the room temperature during each testing situation.

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

Universal Gym. The apparatus used to measure the leg strength was a Universal Gym. This apparatus consists of a series of pulleys and levers used for the purpose of progressive resistance exercises. The particular part of the apparatus used in this study was the leg extensor unit consisting of an adjustable chair and foot pedals which were attached by means of a lever to the weights. Since the weights increased in increments of thirty pounds, two ten pound and one five pound weights were used in order that the subject's strength might be measured to the nearest five pounds. The Universal Gym is illustrated in Figure IV.

III. SELECTION OF THE PHYSIOLOGICAL MEASURES

The use of the bicycle ergometer to measure work load during anaerobic exercise was proposed to be a practical test for determining an individual's anaerobic capacity. Because of the dangers involved in the use of the treadmill it was deemed to be impractical for use in this study. The bicycle ergometer does not involve the subject's body weight in the test for he is sitting during the test.

In the particular test of maximal effort used in this study, the subject was required to hold his breath throughout the exercise period. Because of the apparent lack of validity in testing the anaerobic capacity in the past (6, 19), the author chose to include a mechanical test to attempt to determine the anaerobic capacity. Both Margaria (29) and Costill (5) have investigated this capacity by mechanical means, i.e., the stair run test and the squat weight lift, both of which indicate to some extent the power of the anaerobic system. Breath-holding was employed in an attempt to eliminate the oxidative processes involved in severe exercise. While it is recognized that oxygen is available in myoglobin and haemoglobin association, the rationale behind such a test is really very speculative and the author felt that a maximal test in hypoxic conditions would possibly give some indication of the capacity in question.

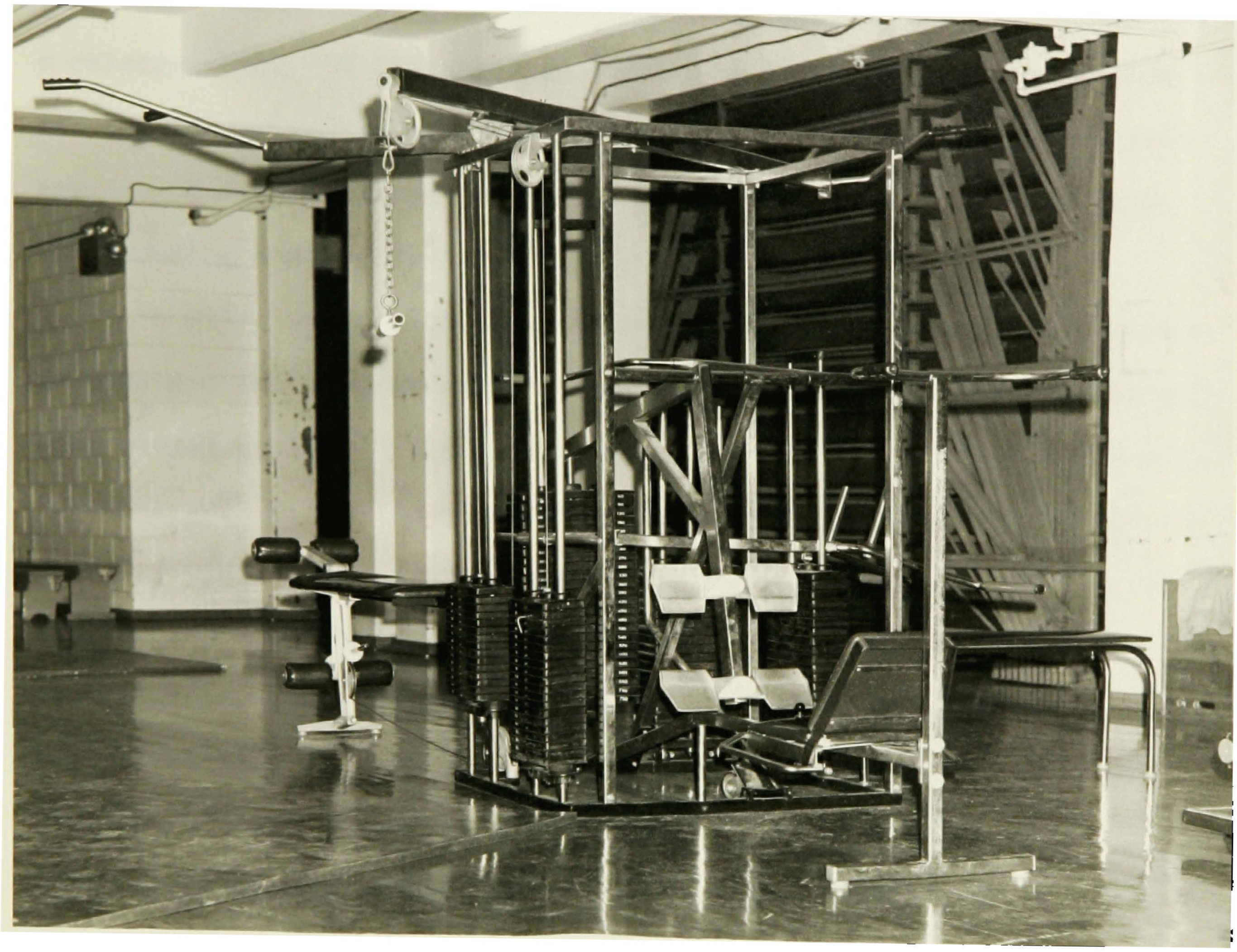


FIGURE IV

THE UNIVERSAL GYM

The test was conducted under two experimental conditions. In one case, the subject wore a mouthpiece leading to the gas collecting equipment in order that his post-exercise recovery gases might be collected and the oxygen debt determined. The oxygen debts of the subjects were then compared to the workload performed to see if there was a relationship. In the other condition, the mouthpiece was not worn for the investigation was concerned only with the amount of work performed. Under both conditions a nosepiece was worn to seal the nostrils during the breath-hold.

A pilot study was conducted previous to the main investigation to obtain a level of exertion which would reliably measure the maximal work output possible under anaerobic conditions. The raw data obtained from the two subjects are contained in Appendix I. After two weeks of pilot testing, the author concluded that three work levels were very similar and that individual differences determined the one to use. The three levels were indicated as follows: (i) a reading of 4.5 on the ergometer scale at a pedal rate of eighty revolutions per minute (2173.68 KPM per minute), (2) a reading of 4.0 on the scale at a pedal rate of ninety revolutions per minute (2173.68 KPM per minute), and (3) a reading of 4.0 on the scale at a pedal rate of eighty revolutions per minute (1932.16 KPM per minute). Other rate and load variations proved to be inadequate, for at lower resistances and higher pedal rates the subjects indicated they could have pedalled longer but they could not hold their breath any longer. At higher resistances and slower paces, the subjects were unable to continue for an appreciable length of time due to rapid onset of local muscular fatigue.

Having determined three levels of exercise, the subjects for the main part of the investigation were then tested. Before the test rides all subjects were required to hyperventilate for one minute in order to increase their breath holding capacity (11). The subject was then seated on the ergometer at a pre-determined seat height so that his leg was slightly flexed at the knee when the pedal was in the bottom position. The pedal was then adjusted so that the subject's preferred leg would push downward to initiate movement in the test. Before commencing to pedal, the subject took two or three deep inhales and exhales, and held his breath on the last deep inhale. A stopwatch was started at the end of the last deep inhale as the subject simultaneously began to pedal, and was stopped to terminate the particular trial, when the subject could no longer hold his breath or continue to pedal at the required rate. The subject was told to push down on alternate pedals for every "click" of the metronome (i.e., one revolution for every two sounds) in order to maintain the required pace. The workload was kept constant by adjusting the indicator on the scale of the ergometer to the required level.

Oxygen Debt Test. When oxygen consumption measurements were to be taken, the same procedure was followed as was used in the bicycle ergometer test except that the subject was also connected to the gas collecting apparatus by means of the mouthpiece. The subject initially hyperventilated through the Triple-"J" valve with the Hans-Rudolf valve turned so that it led from the tubing to the room air. This valve remained in this position throughout the exercise to allow the subject to exhale slightly while breath-holding if he so desired. When the stopwatch was stopped at the completion of the exercise, however, the valve was simultaneously turned to connect one of the Douglas Bags into the system. Gas collection was carried on for seven minutes following completion of the exercise.

Stair Run Test. The stair run test was selected as a measure of anaerobic performance on the basis of the studies by Margaria (26) and Costill (5). The test as described by Margaria was modified by Costill and further modified by the author to suit the available facilities. The author does not feel that the modifications altered the test significantly.

The subject was required to run as fast as possible up twelve stairs, two with each step. A running start of six and one-half feet was allowed to build up speed before running up the stairs. The run was timed from the fourth to the eighth stair, starting on the fourth stair (as illustrated in Figure V) when the subject stepped on the cord attached to the starter switch. The timer stopped when the subject stepped on the contact pad situated on the eighth step. Each stair in the test was 6.5 inches high; each subject moved through a vertical distance of twenty-six inches or 2.167 feet while being timed. The angle of the staircase is thirty-one degrees to the horizontal.

Leg Push Test. Costill indicates that there is a high correlation ($r = .751$) between anaerobic power and squat leg lift. The author feels that although the Universal Gym was used instead of the squat lift, the same physiological measure was tested, i.e., dynamic leg strength. In the test used in this study, the weight factor is not as important as in the test used by Costill because the test is administered in the sitting position. In the test, the subject was seated on the chair and he placed his feet upon the upper pedals. The seat

FIGURE V

STAIRRUN TEST START

was then adjusted so that the angle between the upper and lower leg was eighty degrees. The angle was the same for all subjects so that a smaller man would not have an advantage over a taller man. Each subject was asked how much weight he thought that he could push before attempting his initial trial. If the subject was able to push this amount, the weight was increased in five pound increments to maximum. A rest period of two minutes or more if desired, was given between each trial to allow the subject to recover.

IV. CALIBRATION AND CALCULATIONS

Bicycle Ergometer Workload. The workload was calculated according to the procedure described by Astrand (1). The circumference of the flywheel and the gear ratio of the bicycle ergometer were such that at a pedal rate of fifty revolutions per minute, the subject travelled the equivalent of 300 metres horizontally. When tension was applied to the belt surrounding the flywheel, the deflection of the pendulum scale read the units in kiloponds (KP), where one kilopond is the force acting on a mass of one kilogram at normal acceleration due to gravity (sea level). The braking power (KP's), set by adjusting the belt tension, multiplied by the distance covered (metres) gave the amount of work in Kilopond metres (KPM).

By using the formula:

flywheel circumference X mechanical advantage X rate
X resistance

it is possible to derive two constants, one for the exercises performed at 4.5 X 80 and 4.0 X 90 workloads (2173.68) and one for the exercise performed at 4.0 X 80 (1932.16), where the first number represents the reading on the bicycle ergometer resistance scale and the second number represents the rate of pedalling in revolutions per minute. When these two constants were multiplied by the time in minutes for the respective rides, the amount of work performed in KPM's was found.

Gas Analysis Procedure. The Fisher-Hamilton Gas Partitioner was calibrated for each experiment by performing an analysis of the two reference gases both before and after analyzing the respiratory gas sample. 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 post-sample analysis of each gas yielded only slight differences in chart unit values.

The chart lines were transferred to per cent values by constructing graphs (Appendix I) using the per cent and line values of the reference gases as known points on the graph. Because of the variations in the ambient environment from day to day, it was necessary to produce new graphs for each test situation.

A Bailey Bottle was used to remove the sample gases from the Douglas Bags by way of a small tube of approximately one-quarter inch inside diameter. This sample was then introduced into the gas partitioner by opening the Bailey Bottle valve slowly, allowing half of the air in it to pass into the partitioner. The plunger on the side of the partitioner was then pushed and the helium carried the sample gas into the two analysis columns. Duplicate analyses were performed on each sample.

After the samples had been taken from the Douglas Bags, the bags were vacuumed by means of the chain-compensated gasometer. Before the bag was vacuumed, however, the scale was read and the measure recorded on the data sheet (Appendix E). After the bag was completely vacuumed, the scale was again read and the value recorded. The difference between the pre and post readings was then calculated and recorded. At this point, it was necessary to multiply the difference by the gasometer factor (5.158) to give the volume of the samples. This operation was performed because the gasometer scale recorded in millimeter units. The volume was then multiplied by the conversion factor (STPD) derived from barometric pressure in millimeters of mercury, and the temperature of the test gas in degrees centigrade. A nomogram developed by Robert Darling (4) was used for this purpose. The ventilation rate (VR) for each sample was calculated in litres per minute to the nearest one-hundredth of a litre, by dividing the total corrected volume by the number of minutes in the collection period, which was seven minutes in all cases.

Determination of Oxygen and Carbon Dioxide Percentages. Using the graphs (Appendix I) produced with the use of known gases per cents and number of lines, the per cent by volume of the oxygen and carbon dioxide of the respiratory samples was determined. The mean number of lines recorded for each of the gases was applied to the graph and the percentage of each was extrapolated. Because oxygen and argon are not adequately separated in the gas partitioner, it was necessary to correct each mean oxygen per cent for argon interference in order to obtain the actual oxygen percentage. The argon correction factor developed by Hamilton (16) was used for this purpose. Hamilton developed the formula:

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

Therefore, 0.80 was subtracted from each mean per cent of oxygen to determine the actual per cent. This value was recorded to the nearest one-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. (4) was utilized to gain further values. By inserting the values found for oxygen and carbon dioxide, the respiratory quotient and true oxygen (the number of milliliters of oxygen consumed for every 100 milliliters expired) were calculated and recorded. The true oxygen was then multiplied by the ventilation rate and this value was divided by one hundred to give the oxygen consumption in litres per minute. The formula used in this study was:

$$\dot{V}O_2 \text{ (litres/minute)} = \frac{\dot{V} \text{ gas (litres/minute) X true } O_2}{100}$$

By multiplying the oxygen consumption by the time during which the gas was collected the Oxygen Debt in litres is obtained for the exercise.

V. EXPERIMENTAL PROCEDURE

Testing began on April 12, 1969 and extended until May 21, 1969. All testing was conducted in the Human Performance Laboratory or the Field House at the University of Montana. The pilot study was conducted during February and March.

Athletes. The athletes were tested on the bicycle ergometer in the Human Performance Laboratory on May 7, 8, and 9. The stair run test and the leg push test were conducted on May 20 and 21 due to two important track meets on the weekends following the ergometer test. All subjects were oriented as to the testing procedure and given trial runs on the bicycle ergometer and stair run tests, but due to the simplicity of the leg push test were tested immediately with no practice trials.

The athletes were tested at three levels on the ergometer without the gas collection procedure to determine the level at which they performed best. The following day the subject was again tested at his best performance level, i.e., the level at which he produced the greatest number of KPM's. During this test, the subject was connected to the gas collection apparatus by means of the mouthpiece. The gas collection and analysis procedure has been discussed in an earlier section.

Non-athletes. The training groups were pretested on April 11, 12 and 13. They were given an introduction to the programme and an explanation as to how to ride the bicycle ergometer and the breath-holding technique. Each subject was given a practice ride on the bicycle to orient him to the ergometer. The subjects were told that this was a test ride. The subjects were then given three test rides for which the times were recorded. A sufficient rest period was given between each ride to permit recovery as indicated by a return of the heart rate to the resting pre-exercise level. The day following the bicycle ergometer test, the subject was pre-tested on the leg push test. Care was taken to insure that the angle between the upper and lower leg was constant at the start of the push. The subjects were then asked to achieve their maximum push according to the procedure indicated in the preceding section.

The same procedure was repeated for the post-test which took place between May 18 and 20. All bicycle ergometer tests were conducted in the Human Performance Laboratory and all leg push tests were conducted in the Field House.

All information including the subject's name, weight, height, age, the time of day, last food, hours of sleep the previous night, and other activity was recorded on one or both of two standardized information sheets which appear in Appendices C and E. The raw data for each subject appear in Appendices D and F.

VI. TRAINING

The six athletes were to follow their own training programmes until the time of testing and no additional training was required by the author.

The non-athletes were scheduled to train during their regular weight training class which met at 9:00 A.M. Monday, Wednesday, and Friday of each week during Spring Quarter. The running group trained on the football field immediately to the East of the Field House, and the weight trainers trained on the Universal Gym in the Field House.

The running group followed the training schedule outlined in Table II. The training consisted of a series of progressive and repetitive runs. The runners were required to stride for twenty-five yards both before and after the sprint in each case. The striding consisted of a half speed run to allow the runners to work up to the sprint. The sprint was a full speed run. The subjects performed the stride-run-stride sequence along the length of the field and across the end zones when more space was required for the longer runs. They then walked back to the starting line, beginning each repetition from

TABLE II

TRAINING SCHEDULE FOR RUNNERS

WEEK	NUMBER OF REPETITIONS	STRIDE (yards)	SPRINT (yards)	STRIDE (yards)
1	3	25	50	25
2	4	25	50	25
3	4	25	75	25
4	4	25	100	25
5	5	25	100	25

the same end of the field. The training programme was designed by the author in conjunction with his adviser, Dr. Brian Sharkey, and followed concepts utilized by Wilt (37) and Costill (5). The programme was designed to overload the anaerobic system and, hopefully, produce some training effect on this system.

The weight trainers trained under the guidance of Mr. Gordon Morris, who aided the subjects in developing their own individual programmes of progressive resistance exercises. These programmes were required to contain leg exercises which would develop strength (high weight, low repetition exercises).

Because the runners had enrolled in a weight training course, they too were allowed to follow a weight training programme. The exercises they were allowed to perform, however, were restricted to ones which exercised their upper body alone, so that running was the only training performed specifically for the legs.

CHAPTER IV

ANALYSIS AND DISCUSSION OF RESULTS

I. INTRODUCTION

This chapter presents the data on the various tests performed on both the athletes and the non-athletes. The athletes were examined on four tests to determine if a valid test for anaerobic capacity could be developed. The non-athletes were examined on only two of these tests, to determine if specific training had any effect on the anaerobic capacity and strength, and also to see if strength was related to capacity.

Statistical analysis was limited due to the number of subjects, the restrictions placed on the study by methods of choosing subjects and the variables surrounding each test situation. Because of the small size of the group, the Spearman Rank Order correlation technique (Appendix G) was used to statistically analyze the data obtained on the athletes.

Due to the small size of the non-athlete groups, only means, standard deviations, and the difference between the means of the groups, both pre- and post-training will be presented. No tests of significance were applied to these data.

The data for both the athletes and the non-athletes are presented in Appendices D and F.

II. ANALYSIS OF THE DATA

Athletes

In analyzing the data gathered on the athletes, two sets of scores for KPM's were used. The first set called the KPM mean [KPM($\bar{X}$)] was derived when the subjects were being tested to obtain their best workload-rate combination so that a test might be performed to find their oxygen debt while performing at maximum effort. The second set was called the KPM test [KPM(t)], which was derived when the subjects were tested while wearing the gas collection apparatus. Because both tests were administered under varied conditions, i.e., in one situation the subjects were connected to the gas collecting apparatus, and in the other situation they were not, both sets of data will be considered with respect to the other tests.

KMP to Leg Push. The relationships for both the KPM($\bar{X}$) and the KPM(t) tests compared to the leg push test are illustrated in Figure VI and the data presented in Table III. It is evident that no significant relationship occurs between work output and the ability to push with the legs. However, the Spearman Rho correlation indicates a positive correlation in both cases (Rho equals .471 for KPM($\bar{X}$), and Rho equals .500 for KPM(t)), indicating that there is an increase in working ability, under the test conditions, with an increase in leg strength.

When the influence of the body weight is removed from the bicycle ergometer test (Figure VII), the relationship between KPM(t) and leg push becomes a high negative one (Rho equals -.643). The latter relationship indicates that without weight as a factor in the bicycle

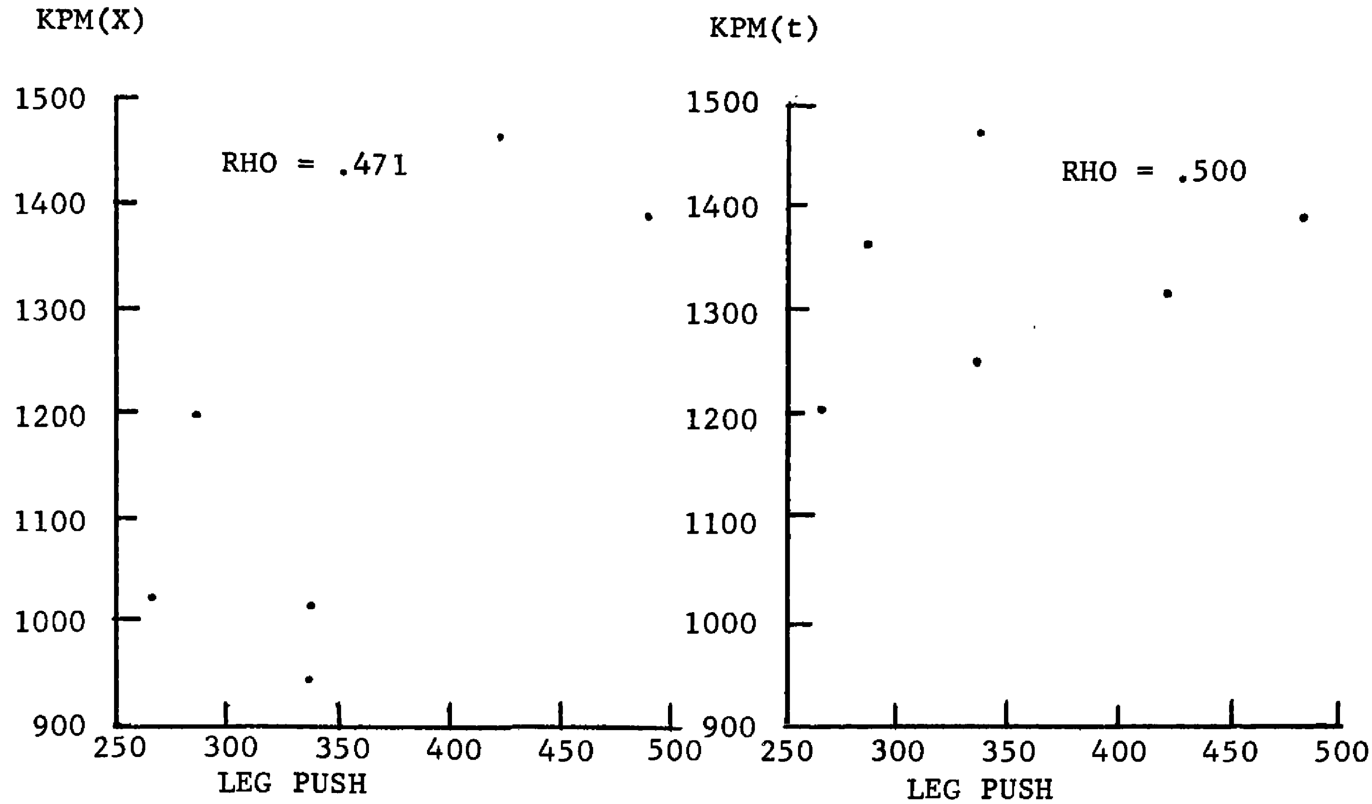


FIGURE VI

LEG PUSH TO KPM

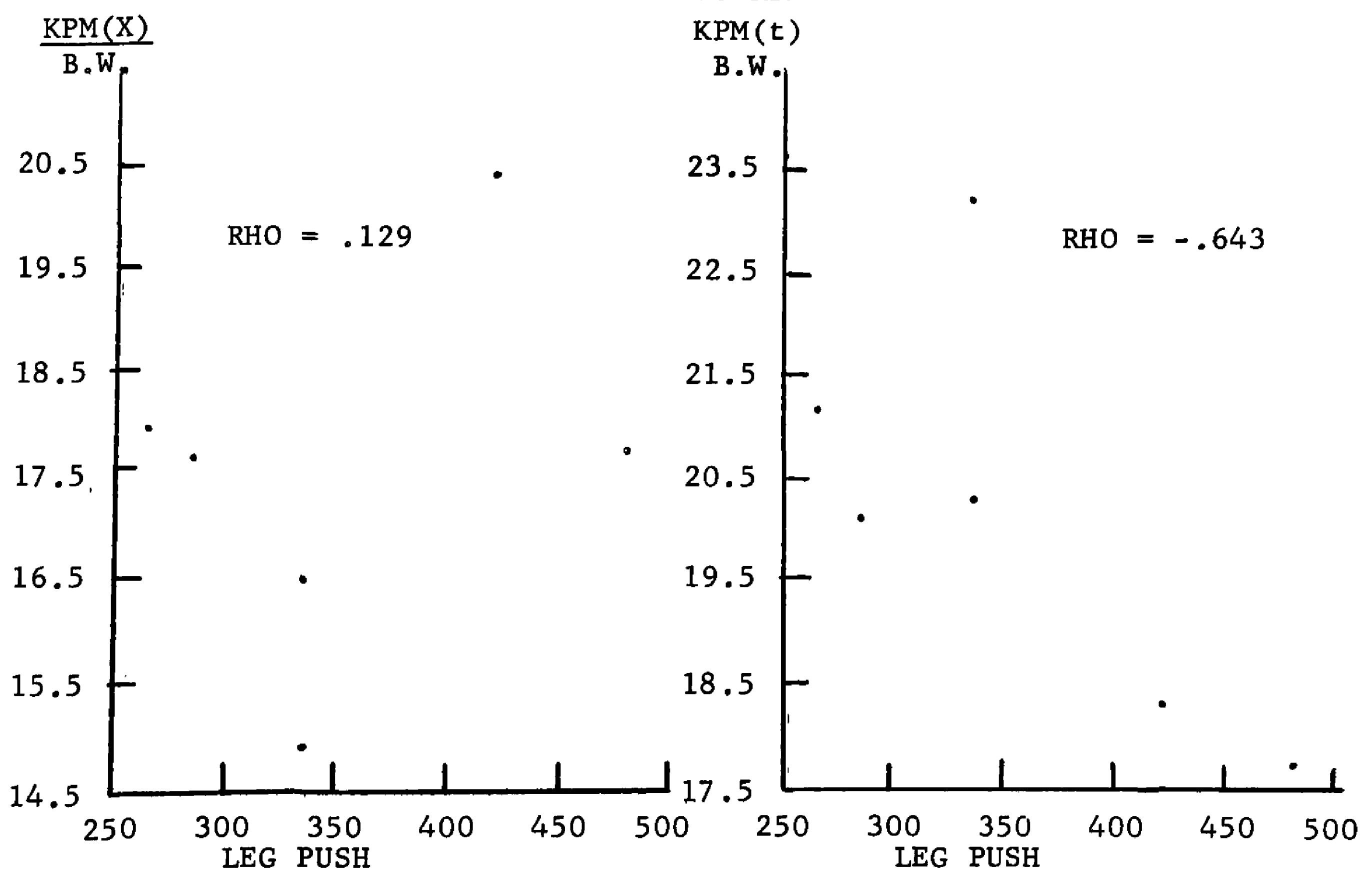


FIGURE VII

KPM PER BODY WEIGHT TO LEG PUSH

TABLE III

RELATIONSHIP OF THE BICYCLE ERGOMETER TEST TO SELECTED PERFORMANCE TESTS

SUBJECT	KPM($\bar{X}$)	KPM($\bar{X}$) / B.W.	KPM(t)	KPM(t) / B.W.	LEG PUSH (pounds)	POWER (Ft.lbs.) / (sec.)	VERTICAL VELOCITY (feet) / (sec.)	OXYGEN DEBT (Milliliters) / (min.)	OXYGEN UTILIZATION (Milliliters) / (kilogram)
R.B.	1466	20.41	1315	18.31	420	361.50	3.90	684.93	9.54
M.H.	942	14.91	1467	23.22	335	343.02	4.25	815.50	12.91
S.L.	1014	16.52	1250	20.37	335	325.00	4.18	479.00	7.81
T.O.	1199	17.70	1365	20.15	285	307.47	3.87	599.67	8.85
D.S.	1388	17.75	1385	17.71	480	354.59	3.84	665.47	8.51
R.V.	1021	17.97	1206	21.22	265	335.20	4.61	706.92	12.44
MEANS	1171.7		1331.3						

ergometer test with gas collection, the workload decreases as the ability to push weight with the legs increases.

When the weight is divided out of the leg push test results, the same trend in correlations is observed, that is the KPM correlations are both higher than the KPM per body weight, although in this instance the KPM(t) relation is much lower than the previous one (Rho equals .200). The other three relationships have remained much the same. The relationships are illustrated graphically in Figures VIII and IX.

<u>KPM to Power</u>. Margaria (29) and Costill (6) have both shown that power, as obtained from a stair run test, will indicate a person's anaerobic power or internal energy production. In Figure X, the relationships between KPM's both mean and test, and power are illustrated. Power has a low relationship to KPM($\bar{X}$) and KPM(t), (Rho equals .486 and .257 respectively). When the body weight was divided out of the work performed the relationship between KPM($\bar{X}$) and power remained the same (Rho equals .486). The relationship between KPM(t) per unit of body weight and power became a negative one but the value still remained low (Rho equals -.371). The data are presented in Table III.

<u>KPM to Vertical Velocity</u>. When the body weight is fractioned out of the power measure the value obtained is the vertical velocity. When compared to KPM($\bar{X}$) and KPM(t), relatively high negative correlations are obtained as indicated in Figures XII and XIII. This agrees in part with the results obtained by Costill (6) who obtained a correlation (Pearson Product Moment) of -.172 between anaerobic power and vertical velocity.

When the weight factor is again fractioned out of the bicycle ergometer measures (Figure XIII), the relationships obtained are very

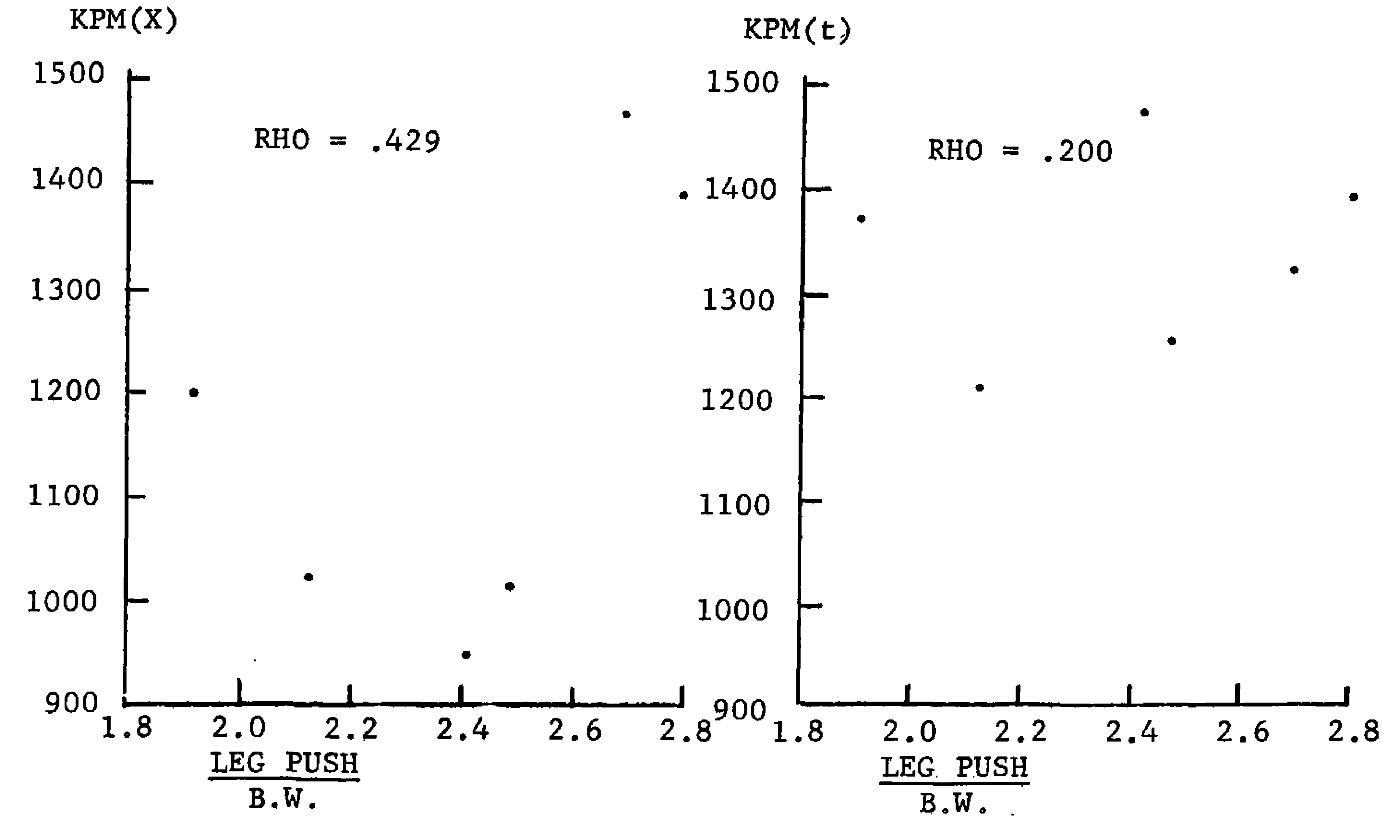


FIGURE VIII

KPM TO LEG PUSH PER BODY WEIGHT

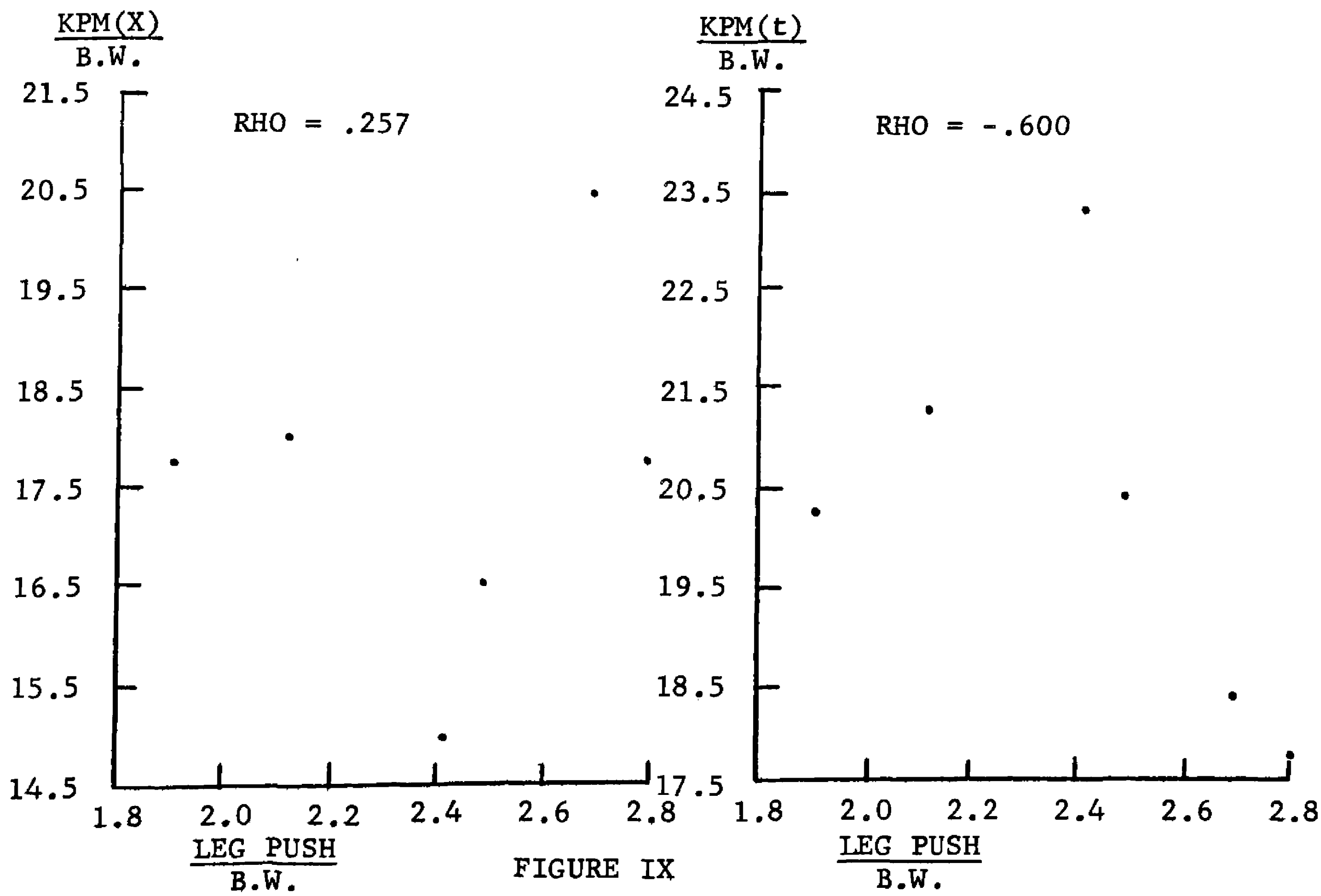


FIGURE IX

KPM PER BODY WEIGHT TO LEG PUSH PER BODY WEIGHT

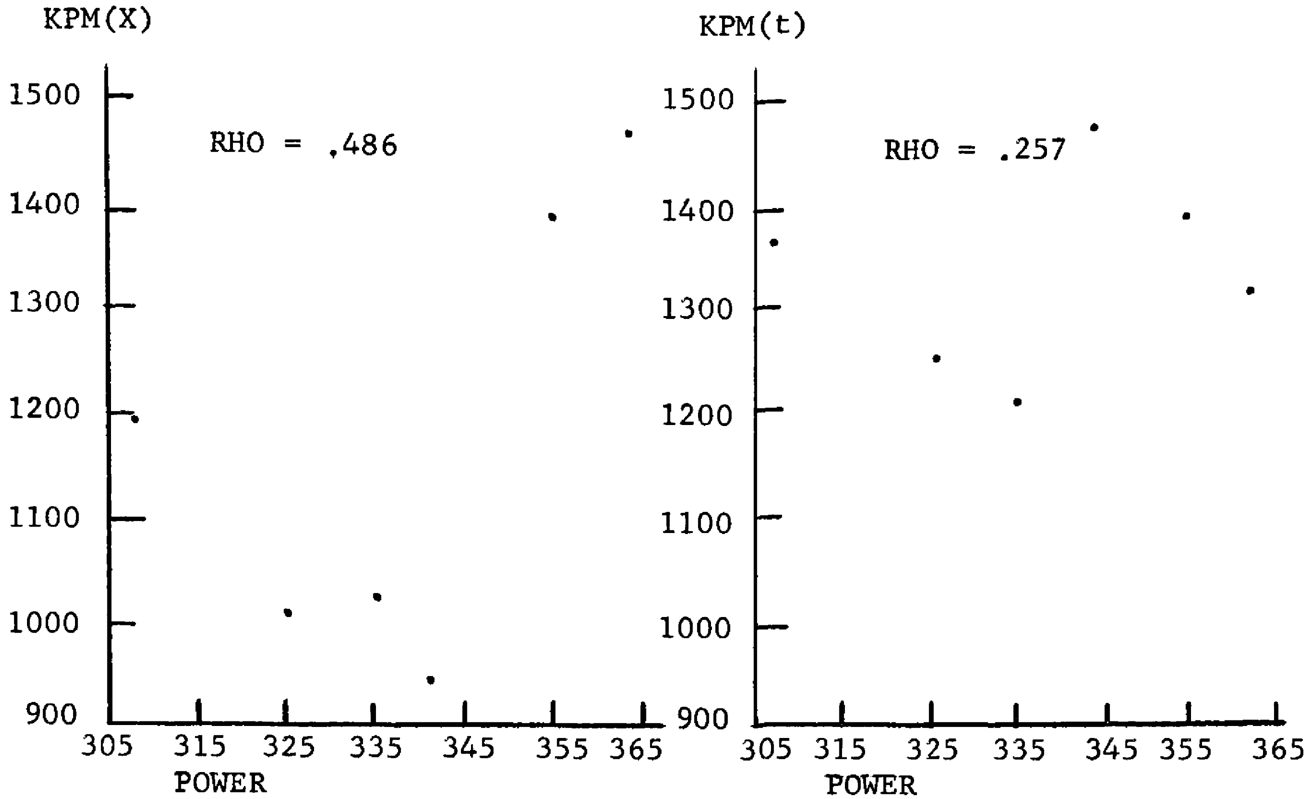


FIGURE X

KPM TO POWER

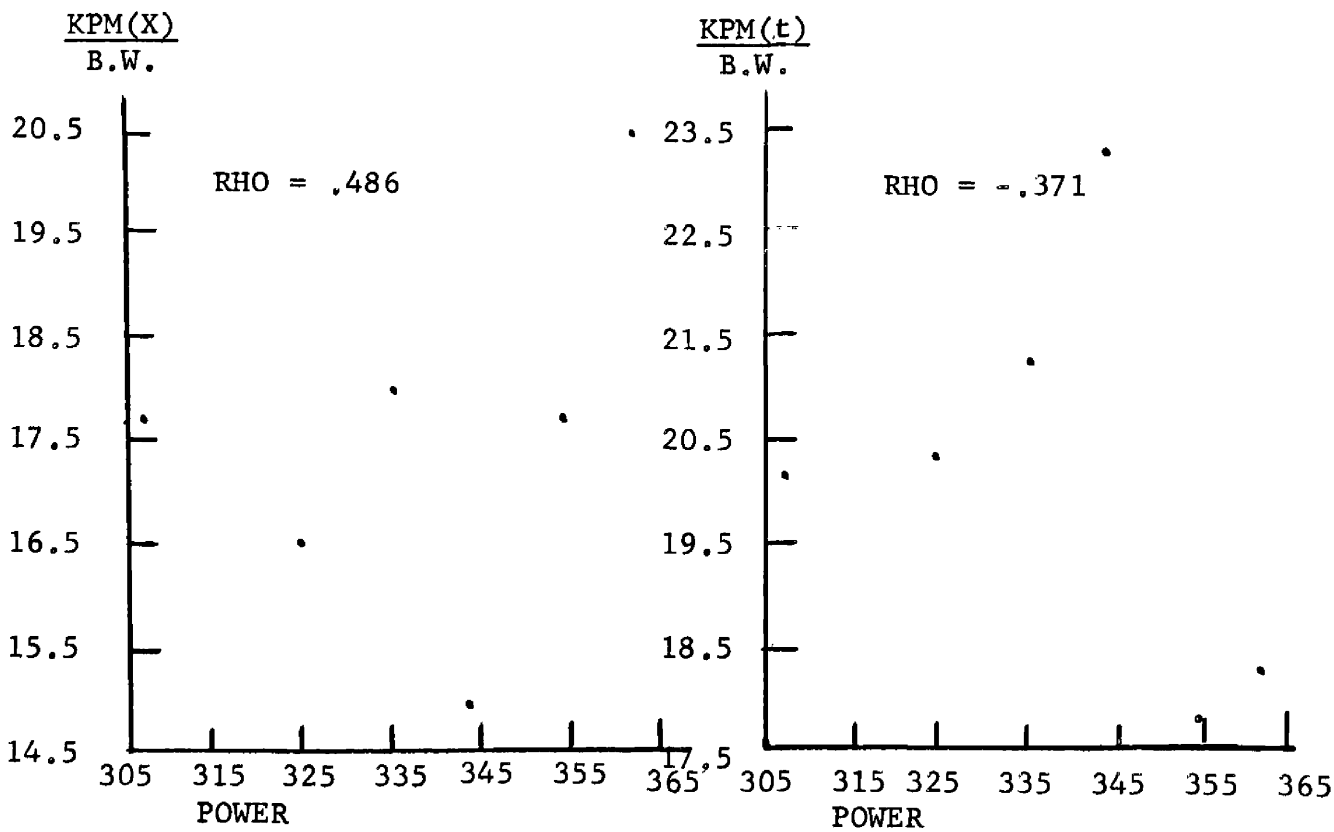


FIGURE XI

KPM PER BODY WEIGHT TO POWER

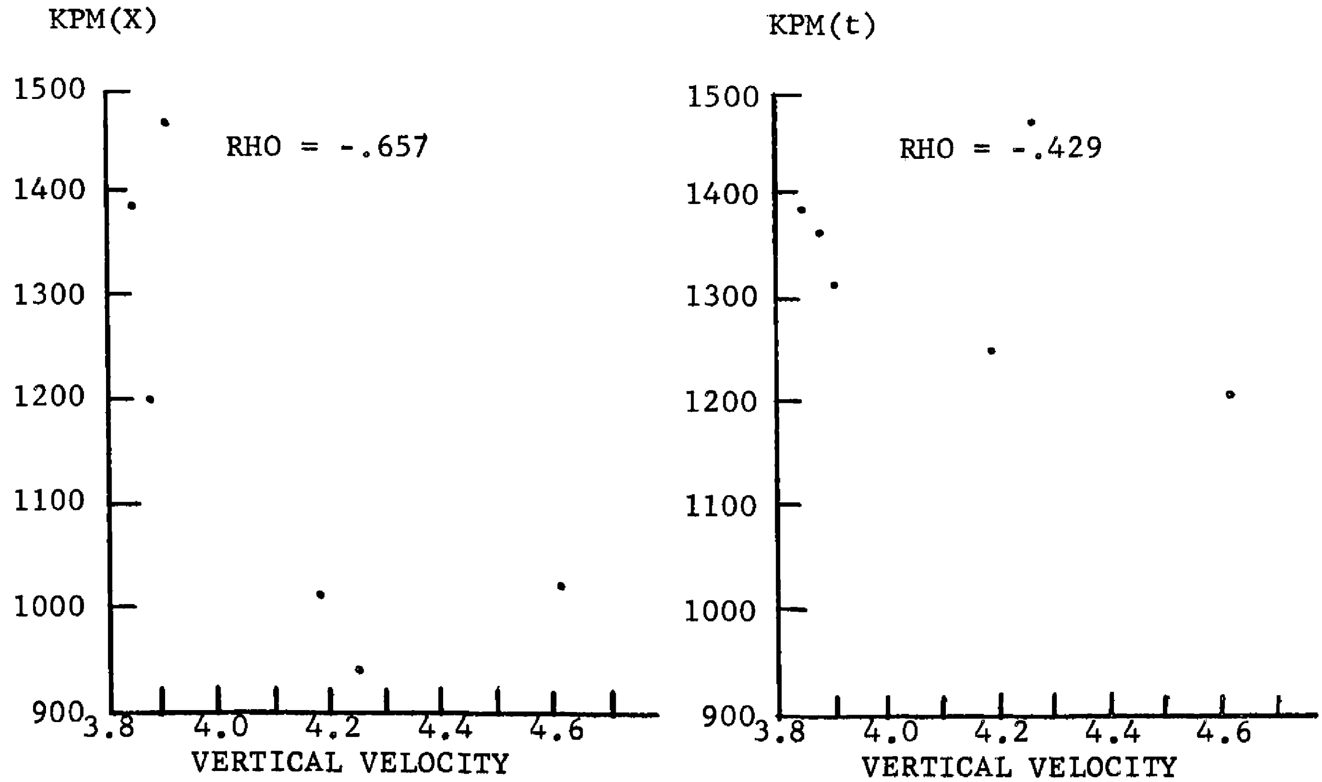


FIGURE XII

KPM TO VERTICAL VELOCITY

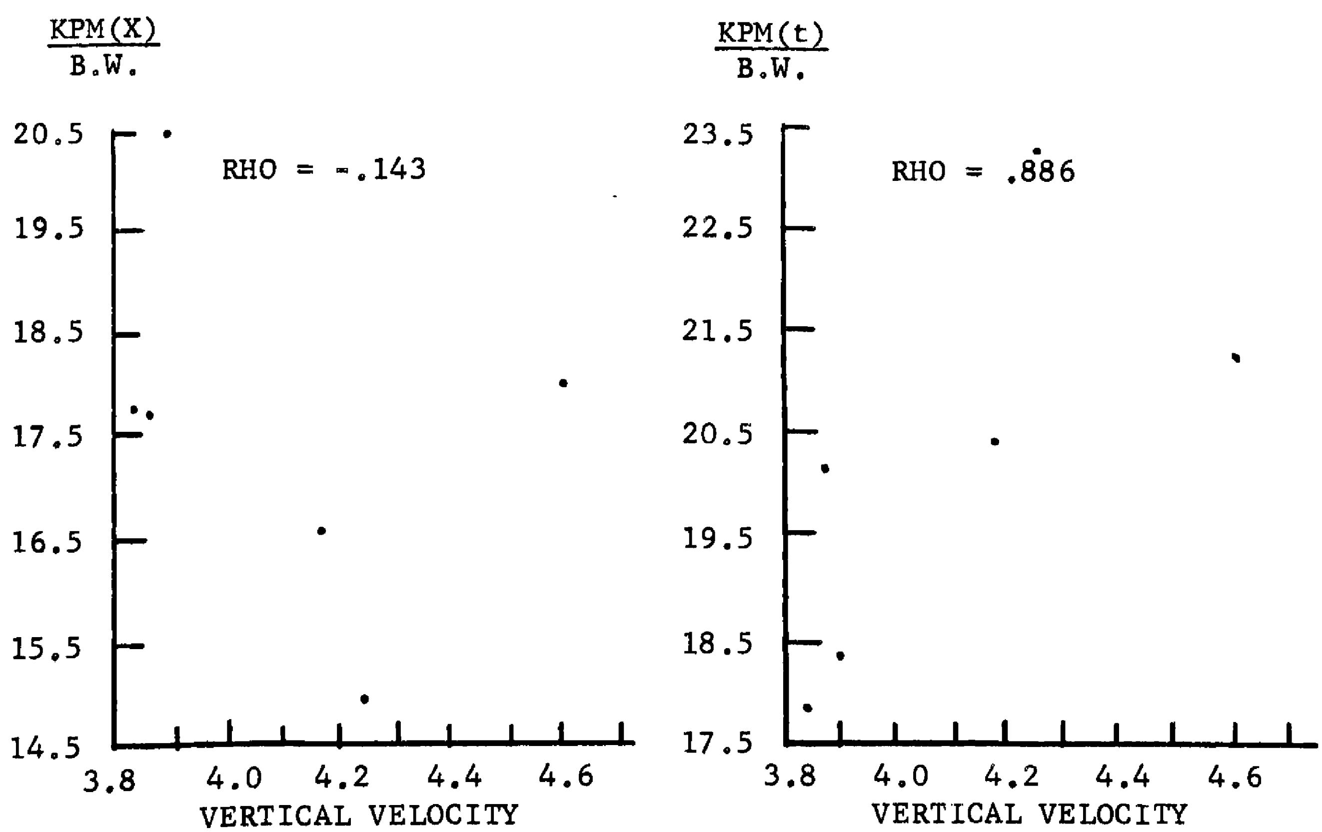


FIGURE XIII

KPM PER BODY WEIGHT TO VERTICAL VELOCITY widely spread. With KPM($\bar{X}$) per unit of body weight and vertical velocity, the Rho obtained is -.143, whereas with the KPM(t) per unit of body weight, the Rho obtained is .886. These results seem to indicate inconsistencies in the measurements between the two bicycle ergometer test situations. The difference in the two situations is shown by the low correlation (Rho equals -.171) between the two, and the mean difference between the two (159.6) (Table III).

KPM to Gross Oxygen Debt. Margaria has proposed that oxygen debt is an indicator of anaerobic capacity (26). In the KPM($\bar{X}$) test, the relationship between the work performed and the oxygen debt is a very low negative one (Rho equals -.200). The difference in the two test situations has already been noted. The lack of gas collection after the KPM($\bar{X}$) test, may account for the fact that there is such a low correlation. The correlation between KPM(t) and oxygen debt is a relatively high one (Rho equals .505) which seems to indicate that when gas is collected in the post-exercise state, there is a good correlation between work performed and anaerobic capacity as measured by the oxygen debt. The values of the gross oxygen debt obtained (without resting values subtracted out) are indicated in Table III. These values agree with what Cunningham and Faulkner (7) found, although they collected gas for twelve minutes after the exercise was completed.

When the weight was divided out in the test situation, the relationship remained about the same (Rho equals .486).

KPM related to Oxygen Utilization. By fractioning out the body weight from the oxygen debt, the oxygen utilization in milliliters per kilogram per minute in the post-exercise condition was obtained. The

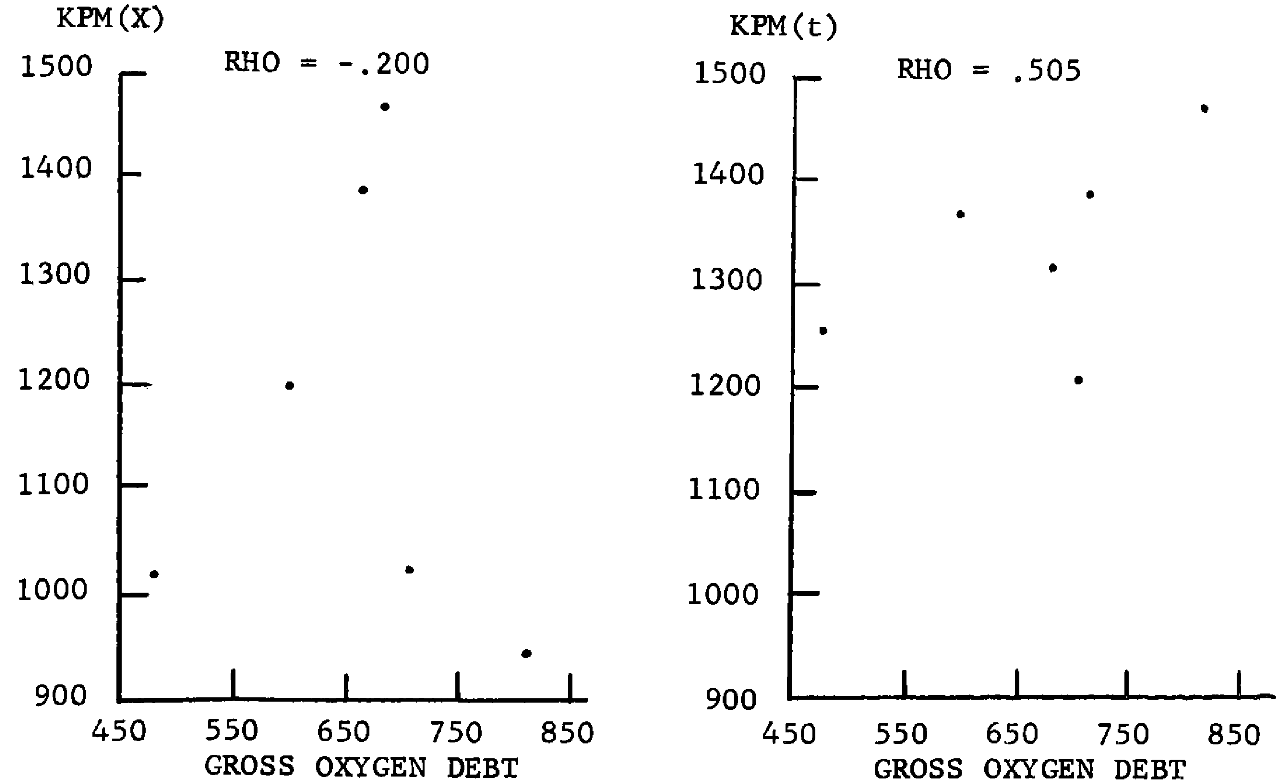


FIGURE XIV

KPM TO OXYGEN DEBT

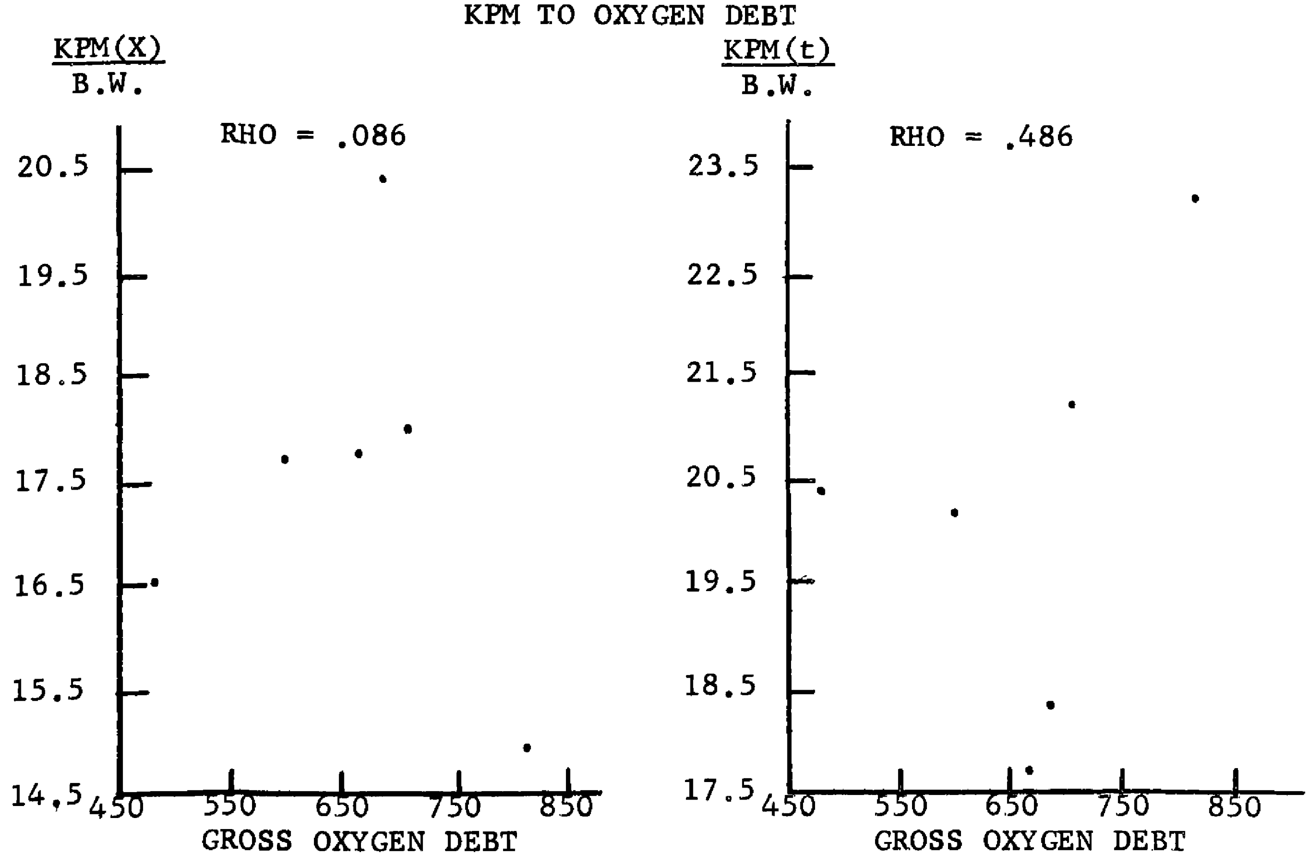


FIGURE XV

KPM PER BODY WEIGHT TO OXYGEN DEBT

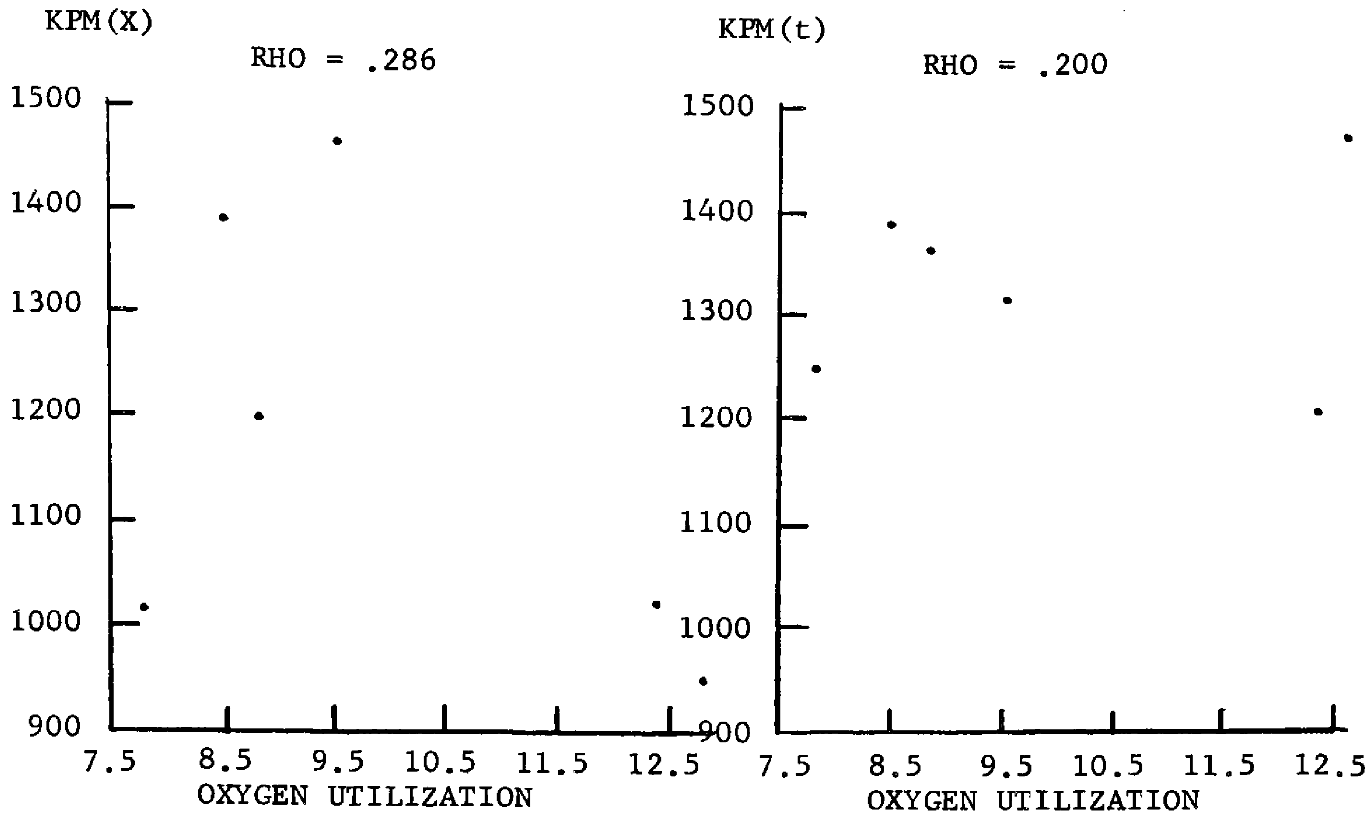


FIGURE XVI

KPM TO OXYGEN UTILIZATION

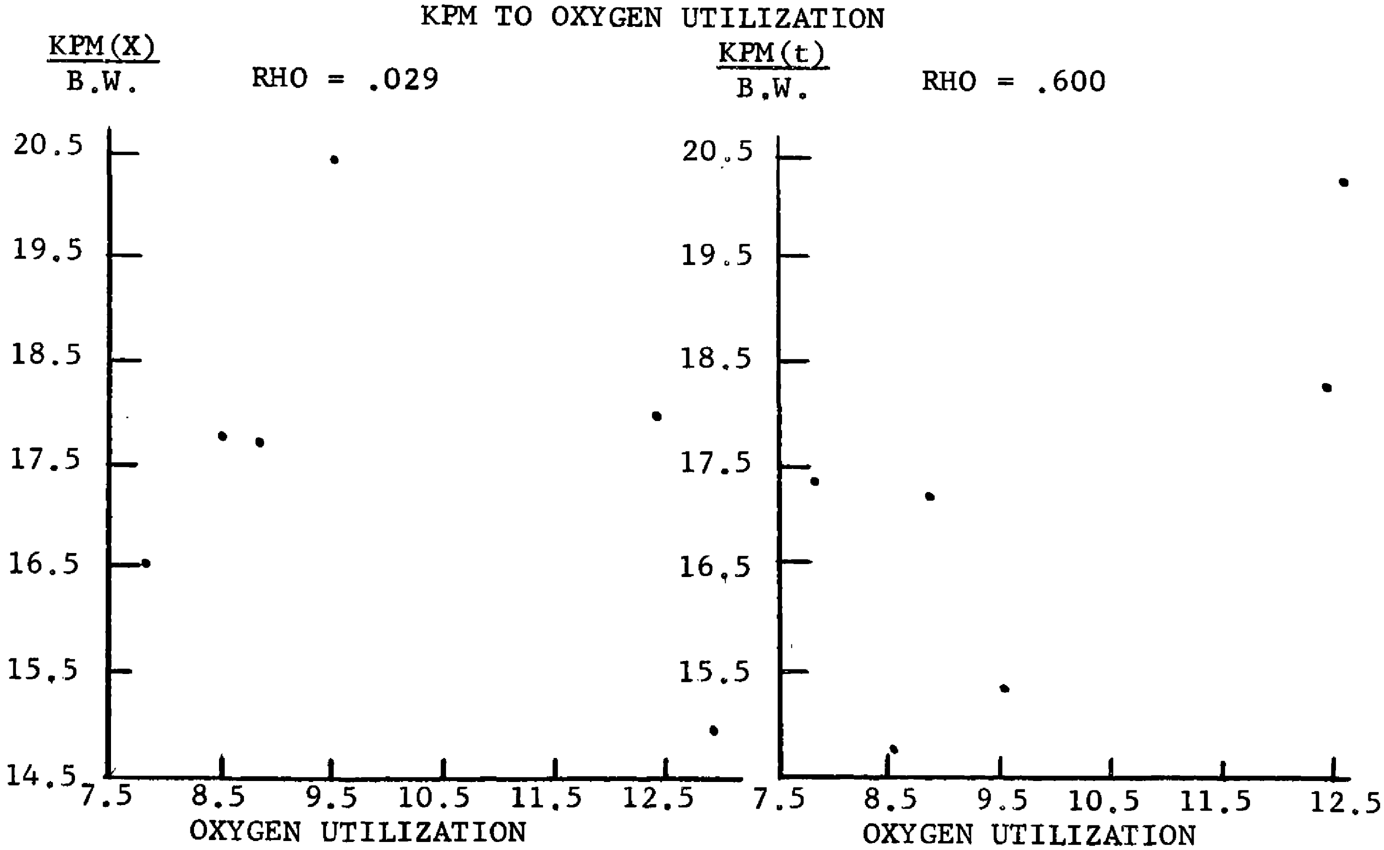


FIGURE XVII

KPM PER BODY WEIGHT TO OXYGEN UTILIZATION relationships are illustrated in Figures XVI and XVII between the oxygen utilization and the KPM and KPM per unit of body weight for both mean and test stiuations. The correlations calculated for both KPM($\bar{X}$) and KPM($\bar{X}$) per unit of body weight are very low (Rho equals .286 and .029). This low correlation also occurs between KPM(t) and oxygen utilization (Rho equals .200) but a high positive correlation exists between KPM(t) per unit of body weight and oxygen utilization (Rho equals .600). The high positive correlation may be partially explained because both factors have had the body weight fractioned out, and it was after this test situation that the gas was collected. The data for the situations are presented in Table III.

Other Relationships. Other relationships were investigated to determine the correlations between the various tests administered. These relationships are illustrated in Figures XVII through XXI with correlations as indicated. There is a positive correlation between oxygen debt, a measure of anaerobic power as indicated by Margaria (26), and vertical velocity (Rho equals .543). This relation contradicts what Costill (6) has found. He obtained a correlation (Pearson Product Moment) of -.172 between anaerobic power and vertical velocity.

The other relationships are as indicated by the graphs. All of these seem to show the lack of reliability of the testing procedure used, for there does not seem to be any consistent pattern emerging from the various relationships. The various test correlations are listed in Appendix G.

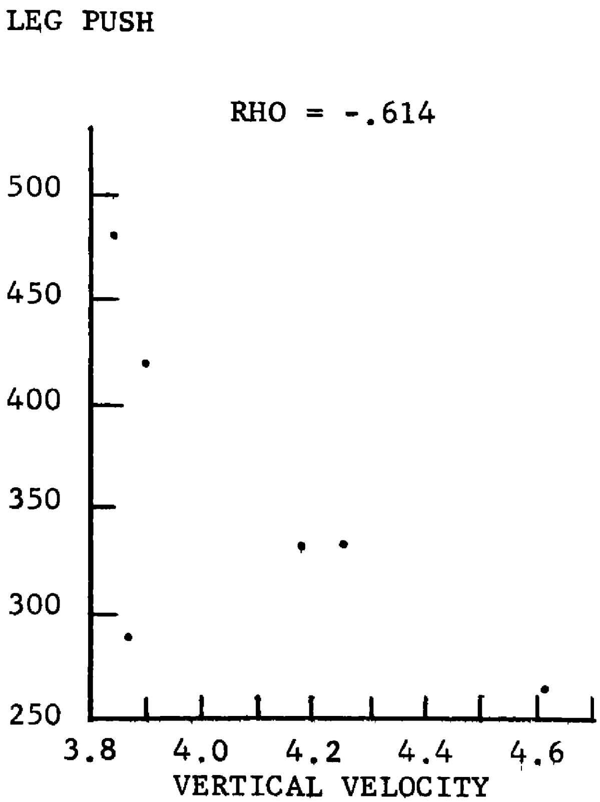


FIGURE XVIII

LEG PUSH TO VERTICAL VELOCITY

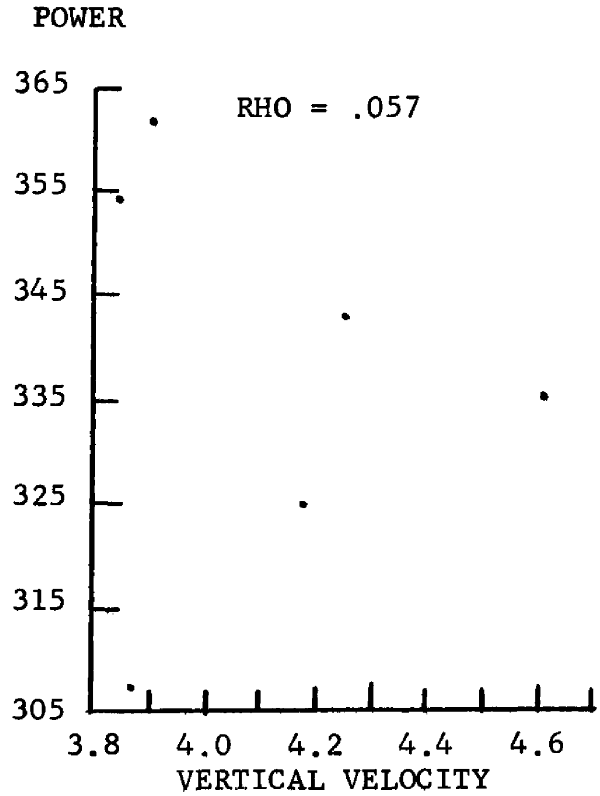


FIGURE XIX

POWER TO VERTICAL VELOCITY

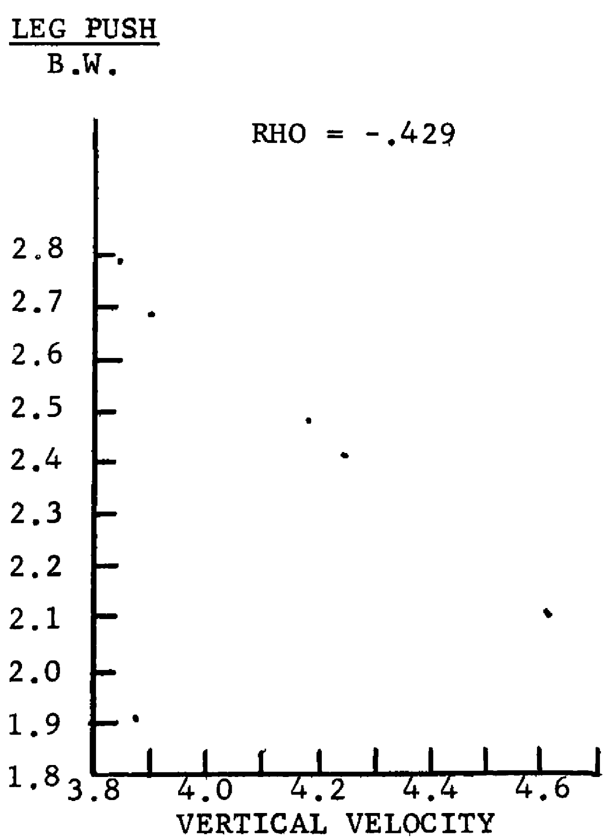


FIGURE XX

LEG PUSH PER BODY WEIGHT TO VERTICAL VELOCITY

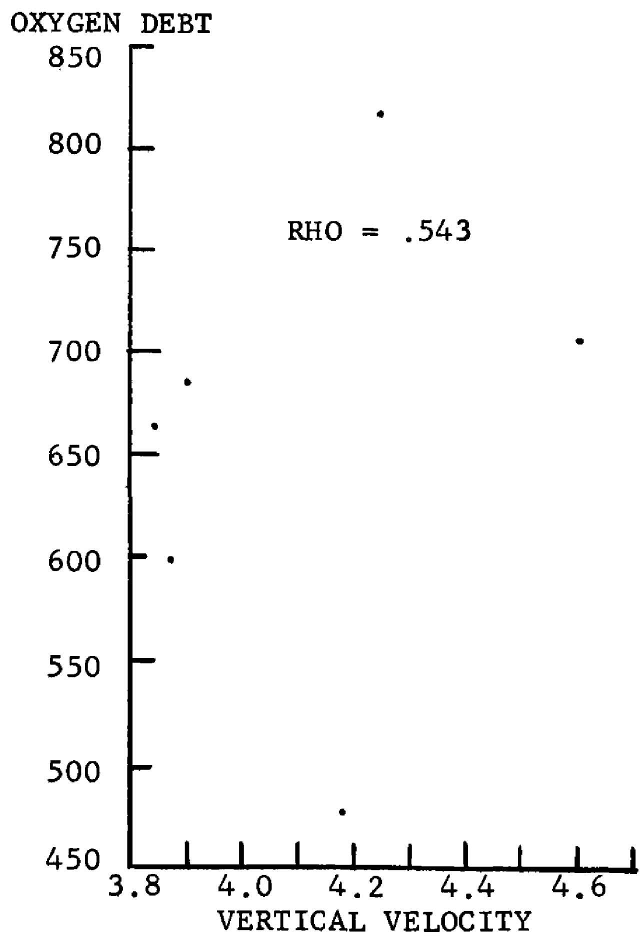


FIGURE XXI

OXYGEN DEBT TO VERTICAL VELOCITY

Non-Athletes

The raw data, both pre- and post-training, for the non-athletes are listed in Appendix D. No statistical analyses were performed on the data because of the size of the groups and the lack of random sampling used to determine the groups.

The group means are presented in Table IV. The runners seemed to obtain a training effect with respect to the amount of work they were able to perform on the bicycle ergometer. The mean difference between the two trials measured in KPM's was 141, with the post-training situation being greater. The weight trainers however, did not appear to attain this same increase after the training period, with a group mean increase of thirty-four KPM's. On the other hand, the weight training group did experience an increase in the ability to push weight with the legs. The group mean increased thirty-nine pounds in the post-training test as compared to only six pounds for the runners (Table IV).

Individually, with respect to the amount of work produced on the bicycle ergometer, two of the three runners improved their ability to work under the test conditions. The third runner remained much the same with only a slight increase. The weight trainers also had two individual increases. Looking at other information recorded at the time of the test, weight trainer M. L., who increased his work output a great deal, had only five hours sleep the night before the pre-test which may have effectively lowered his ability to perform on the bicycle. This factor may account for the large difference in his pre- and post-training scores. The same rationale might also apply to

TABLE IV

MEANS, STANDARD DEVIATIONS, AND MEAN DIFFERENCES
OF DATA ON NON-ATHLETES

		PRE-TEST MEAN	PRE-TEST STANDARD DEVIATION	POST-TEST MEAN	POST-TEST STANDARD DEVIATION	MEAN DIFFERENCE
RUNNERS	KPM	1162.0	66.77	1303.00	79.93	141.0
RUNNERS	LEG PUSH	370.00	40.83	363.33	49.03	6.67
WEIGHT TRAINERS	KPM	1140.0	119.35	1173.75	64.53	34.0
WEIGHT TRAINERS	LEG PUSH	363.75	24.85	402.50	36.32	39.0

runner R. V. K. who had only five hours sleep before the post-test, and had remained essentially the same as in his pre-test effort.

Of the other two weight trainers, one remained the same in work output from pre- to post-test, while the other decreased in his ability to perform on the bicycle ergometer.

In the leg push test, all of the weight trainers were able to push more weight after the training period. Whether this was due to a physiological training effect or a learning effect is not clear. Indications seem to point to a definite physiological benefit being derived from the training. Observations of the post-test scores of the runners on the leg push test, where two decreased in the amount of weight pushed, and one remained the same, suggests that there was a physiological rather than a psychological effect.

III. DISCUSSION OF THE RESULTS

The results of the study point out many interesting facts concerning the nature of the test employed in the investigation of the anaerobic capacity.

By analyzing the Spearman Rank Order Correlations between the tests conducted (Appendix F), an apparent difference is seen to occur between the KPM($\bar{X}$) and KPM(t) when compared with other tests. Although the difference is not very large in some cases, the trend appears to indicate that there is a difference between testing for anaerobic capacity with and without the gas collecting apparatus. This difference is most evident when the two test situations are correlated (Rho equals -.171), which suggests that the tests are not in fact related.

This difference could be attributed to many factors. The author felt that the subjects' unfamiliarity with the equipment and the test, though an orientation session was given, was the main cause of the lack of relationship between the two trials. Perhaps if more trials were run a more reliable result would ensue and a reduction in the psychological inhibitions that Knuttgen mentions might follow (21). The generally improved performance on the test when gas was to be collected in the post-exercise state may be accounted for by the fact that the author encouraged the subjects to give extreme all out effort as this was to be the final testing situation. Because both test situations, with and without the mouthpiece, yielded different results, the author chose to report both situations as they related to the other tests.

The results obtained when the bicycle ergometer test was compared to the leg push test, indicated that a slight relationship exists between the two tests (Rho equals .471 for KPM($\bar{X}$) and Rho equals .500 for KPM(t)). Mechanically speaking, this would seem logical since both tests apparently require dynamic leg strength. However, by observing the training results this hypothesis does not seem to be true. The results obtained when the body weight was fractioned out of the tests, are either low positive or high negative results (Appendix F). These results do not indicate a good positive correlation between the two tests.

Costill (6) has found a high correlation (r equals .751) between his squat weight lift and the anaerobic power as determined by Margaria's stair run test (29). In the present study, the author has also found a high correlation (Rho equals .757) between the leg push test and power as measured from the stair run test. Costill said that the high correlation which he found was due to the weight factor involved in both, but when the weight of each subject was divided out of the leg push test (leg push/body weight), the Rho remained the same (.771). These results substantiate the findings of Costill that the leg push test is a good indication of the anaerobic power of an individual. The leg push test was the only test which showed a good relationship to power. With respect to this relationship, Costill states:

> At first one might conclude that the test of anaerobic power is a function of dynamic leg strength, but further analysis reveals a significant correlation between squat weight lift and body weight. Body weight might account for the relationship between squat lift and anaerobic power, since the body weight is utilized in calculating anaerobic power.

The author does not agree completely with Costill, for as will be discussed at a later time, training with progressive resistance exercises does increase the ability of the subject to push more weight, and although the subjects did gain a slight amount of weight, the increases in weight pushed appear to be manifestations of a training effect rather than the subject's increased body weight. Thus the findings of this study tend to agree that power is a function of dynamic leg strength as is of course the leg push test. Power, however, is not fully dependent on this factor as is leg push. Therefore power may be an indication of the degree of anaerobic metabolism. This possibly was substantiated to a certain extent by the relationship between the oxygen debt and power (Rho equals .486) which although not very high, was definitely higher than the relationship obtained between oxygen debt and the leg push test (Rho equals -.100). Thus it would appear that what Costill has said may not be totally correct. Possibly the leg push test does not really indicate the anaerobic power but is merely a function of dynamic leg strength. On the other hand, dynamic leg strength may be an indication of anaerobic power. From the information read and the data gathered the author is unable to prove either of these statements.

The fact that power is an indication of anaerobic metabolism is further substantiated by inspecting the relationship between vertical velocity (derived from power by fractioning out the weight of the subject) and oxygen debt (Rho equals .543). Most sources agree with Margaria that the oxygen debt is a good measure of the anaerobic power, although Hermansen does oppose this view. The oxygen debts obtained by the author are very close to those obtained by Cunningham and Faulkner (7), who collected gas for twelve minutes after the exercise. They found net oxygen debts ranging from 4.4 to 8.5 litres for the twelve minutes (approximately .3 to .7 per minute). In this study the author found gross oxygen debts (resting oxygen consumption not subtracted) of between .479 and .815 litres per minute. When a resting rate of between .200 and .250 litres is subtracted from these values and the time factor considered, the oxygen debts recorded in this study are very close to those obtained by Cunningham and Faulkner, as well as those of Robinson and Harmon (33). The larger oxygen debts found by Cunningham and Faulkner might be accounted for by the higher weights of their subjects as opposed to the subjects used in this study (mean difference equals 34.1 pounds). Therefore, with respect to this data and the majority of the literature investigated, the author will assume that the stair run is in fact an indication of the anaerobic power of an individual. However, to agree with Hermansen, the degree to which this test does indicate anaerobic power is not known. Because the stair run test is not an exhaustive test, one must conclude that it does not express to any degree the capacity of the anaerobic system, if in fact the capacity can be expressed. The test does not use up the store of available ATP, and does not require glycolysis to occur to any extent. Thus in no way does it approach the limit of anaerobic work.

The next question to consider is the relationship between the bicycle ergometer test and the anaerobic capacity, the essence of the investigation. By looking at Appendix F one may readily see that a wide variation in results occurs when the two situations of the bicycle ergometer test are compared to the other tests. The KPM($\bar{X}$) and power show a fairly good relationship (Rho equals .486). However, when compared to oxygen debt, the correlation becomes low and negative (Rho equals -.200). This situation is almost reversed when KPM(t) is compared to power and then to oxygen debt (Rho equals .257 and .505 respectively). Thus it is difficult to draw any definite conclusions about the validity of the bicycle ergometer test as an indication of anaerobic power and consequently capacity. This fact if further substantiated when the Rho's for the relationships between both KPM's and vertical velocity are inspected (Rho equals -.657 and -.429). It is interesting to note that a high correlation exists between KMP(t) and vertical velocity when the body weight is fractioned out of KPM(t) (Rho equals .886). The significance of this relationship is not understood by the author. However, it may be explained by the fact that both are now independent of the body weight. Thus possibly there is a positive relationship between the bicycle ergometer test and anaerobic power, although to so conclude would be very speculative at this point. The last factor of the bicycle ergometer test (KPM(t) per unit of body weight) is again the only one of four factors which correlates to any appreciable degree with oxygen utilization (Rho equals .600), while the other three have very low positive or negative correlations (Appendix F).

Having looked at the data, it appears that there is much conflicting evidence surrounding the validity or application of the proposed test as a measure of anaerobic capacity. The results would seem to agree with Hermansen (18) who has stated that no valid test yet exists to measure the anaerobic capacity. Because of the contradictions evident in the data presented, it would appear that not only is there no test to determine the anaerobic capacity, but there is no real way to delineate the capacity. The metabolic processes may be known, but to analyze them from a mechanical approach at this time seems to be an impossibility. Some of the results do indicate that the study was in fact directed in the proper area however; for a maximal test of anaerobic metabolism lasting in the area of forty seconds, was used. Margaria has said that this was approximately the capacity of the anaerobic system to perform.

The final issue to discuss is the effect of training on the anaerobic capacity. After the training programme there was a general increase in the ability of the subjects to perform work on the bicycle ergometer. This was especially true in the case of the runners. It does appear that those who trained on the weights alone had a lower increase in their ability to work on the bicycle ergometer than did the runners. Whether this training effect had to do with increased oxygen debt capacity, tolerance to lactic acid in the system, an ability to better use available exergonic materials or other factors is not known for no metabolic functions were measured in the training study. Thus the metabolic manifestations of the training programmes can only be assumed to be the same as those found by other authors (7, 18, 37).

The weight trainers did increase their leg strength to a greater degree than the runners, and performed much better on the leg push test than did the running group. All of the weight trainers increased the amount of weight pushed, whereas one runner remained the same and the others decreased in the amount of weight pushed. The increase in the ability of the weight trainers is evident from the type of exercises with which they trained, i.e., high weight-low repetition exercises which will increase strength of the muscle group exercised. The results would seem to indicate and substantiate what has been said previously, that the leg test is more dependent on dynamic leg strength than on anaerobic power. Even though the weight trainers have increased their leg strength, their ability to ride on the bicycle ergometer under test conditions was not increased. Thus the bicycle ergometer test used in this study was not greatly dependent on dynamic leg strength. The author assumes that the test measures something else, a quality which presently eludes definition. Montoye (30) suggests that training will positively effect breath-holding ability. This may be all that the test has inspected, although indications seem to point to other factors being involved.

The relationship between the anaerobic capacity, as measured by oxygen debt and performance has been investigated in another study concurrent with this one (35).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

The purpose of this study was to investigate the validity of a proposed bicycle ergometer test to indicate the anaerobic capacity. As a sub-problem, the study investigated the effects of training on the anaerobic capacity.

Six athletes from the University of Montana Track Team served as subjects for the battery of tests administered in the main problem of the study. Seven non-athletes from a weight training class at the University served as subjects in the sub-problem. They were divided into two groups: one to test the effects of progressive resistance exercises employed in a training programme, and the other to test the effects of running as used in a training programme for the development of anaerobic capacity. A pilot study was initially performed on two volunteers to determine the load and rate variations to be used in the bicycle ergometer test.

Relationships between the bicycle ergometer test and other selected physiological tests were drawn from the data collected on the athletes. It was found that no really good relationships existed between the test, divided into two parts because of the nature of the circumstances under which it was administered, and other selected tests. There were some high correlations however between the KPM(t) test as defined earlier and the gas measurement tests. A pattern of relationships did not emerge, thus leaving the author to conclude that no real proof existed for the validity of the test in question to serve as a measure for determining anaerobic capacity. It was evident in the testing situations that breath-holding was a definite factor in limiting the duration of the test ride. The data analyzed seemed to indicate that a test involving pushing maximum weight with the legs is mainly dependent on the dynamic leg strength of the individual and is not a good indication of anaerobic power, although more work needs to be done in this area.

The sub-problem regarding the effects of training produced results which seem to agree with what previous researchers have found. The results indicate that training does have a beneficial effect on the anaerobic system. It was beyond the scope of this study to say in what manner the system was benefited.

II. CONCLUSIONS

The results of this study indicate the following conclusions:

A. A bicycle ergometer test for maximum work output while breath-holding does not appear to be a valid indication of the anaerobic capacity.

B. The ability to hold one's breath plays an important role in the test and possibly detracts from what the test is supposed to examine.

C. There are many extraneous factors involved to alter a test of such short duration and high intensity.

D. The leg push test seems to be highly dependent on dynamic leg strength.

E. Training causes an increase in either breath-holding ability or ability to perform work on the bicycle ergometer or both.

F. It is very difficult to separate anaerobic metabolism from aerobic metabolism and thus develop a test to investigate the former.

III. RECOMMENDATIONS

Based on the results of this study, the following recommendations for further study are proposed:

A. Further research should be conducted into the role of anaerobic metabolism in exercise and how to delineate and test anaerobic capacity, possibly through the use of a short maximal effort test that does not involve breath-holding.

B. Further studies concerning anaerobic metabolism should be undertaken to determine more about its function in overall performance. The relationship of anaerobic and aerobic metabolism should be investigated in an attempt to isolate the former and determine its limits.

C. Further studies concerning the effect of training, for example what constitutes an adequate stimulus for change in anaerobic capacity, should be undertaken.

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APPENDICES

APPENDIX A

PHYSICAL CHARACTERISTICS OF THE ATHLETES

APPENDIX A

PHYSICAL CHARACTERISTICS OF THE ATHLETES

SUBJECT	WEIGHT IN POUNDS	HEIGHT IN INCHES	AGE IN YEARS
R.B.	158	73.0	19
M.H.	139	71.0	22
S.L.	135	69.5	19
T.O.	149	72.0	19
D.S.	172	73.5	21
R.V.	125	68.0	21
MEANS	146.3	71.2	20.2

APPENDIX B

PHYSICAL CHARACTERISTICS OF THE NON-ATHLETES

APPENDIX B

PHYSICAL CHARACTERISTICS OF THE NON-ATHLETES

SUBJECT	WEIGHT IN POUNDS		HEIGHT IN INCHES	AGE IN YEARS
	PRE	POST		
M.L.	152	149	70.0	19
G.L.	153	153	68.5	19
J.M.	148	153	69.0	18
T.O.	172	171	74.0	20
R.V.K.	169	170	71.0	19
B.W.	158	160	74.0	18
M.Z.	176	179	71.0	19
MEANS	161.1	162.1	71.1	18.9

APPENDIX C

SAMPLE DATA RECORD SHEET FOR BICYCLE ERGOMETER, STAIR RUN AND MAXIMAL OXYGEN TESTS

APPENDIX C

SAMPLE DATA RECORD SHEET FOR BICYCLE ERGOMETER, STAIR RUN, AND MAXIMUM OXYGEN TESTS

NAME	AGE	WEIGHT (lb)	HEIGHT	HOURS SLEEP	LAST MEAL (hrs)	4.5 X 80 KPM	4.0 X 80 KPM	4.0 X 90 KPM	4.5 X 80 KPM	TEST AT KPM	LEG PUSH (lbs)	STAIR RUN TEST			OXYGEN DEBT (litres)
						TIME	TIME	TIME	TIME	TIME		TRIAL 1	TRIAL 2	TRIAL 3	

APPENDIX D

DATA COLLECTED FOR ATHLETES AND NON-ATHLETES

APPENDIX D

RAW DATA COLLECTED FOR ATHLETES

NAME	AGE	WEIGHT (lb.)	HEIGHT	HOURS SLEEP	LAST MEAL (hrs)	4.5 X 80 KPM	4.5 X 80 TIME	4.0 X 80 KPM	4.0 X 80 TIME	4.0 X 90 KPM	4.0 X 90 TIME	4.5 X 80 KPM	4.5 X 80 TIME	TEST AT	KPM	TIME	LEG PUSH (lb)	STAIR RUN TEST TRIAL 1	STAIR RUN TEST TRIAL 2	STAIR RUN TEST TRIAL 3	OXYGEN DEBT (litres)
RAY BALLEW	19	158	6'1"	8	12	1385	38.2	1269	39.4	1663	45.9	1467	40.5	4.5 X 80	1315	36.3	420	55.5	58.5	56.0	.684
MICK HARRING-TON	22	139	5'11"	8	4	1076	29.7	966	30.0	1050	29.0	811	22.4	4.5 X 80	1467	40.5	335	55.0	52.0	51.0	.815
STEVE LINSE	19	135	5'9"	8	2.5	1463	40.4	869	27.0	1061	29.3	1113	30.7	4.5 X 80	1250	34.5	335	55.0	51.9	55.0	.479
TIM O'HARE	19	149	6'0"	6	3	1267	35.0	893	27.7	1330	36.7	1375	38.0	4.5 X 80	1365	37.7	285	67.0	66.0	56.0	.599
DUANE	21	172	6'1"	7.5	12	1308	36.1	1207	37.5	1315	36.3	1641	45.3	4.5 X 80	1385	38.2	480	56.5	64.5	63.0	.665
RAY VELEZ	21	125	5'8"	8	1	1069	29.5	856	26.6	1113	30.7	1093	30.2	4.0 X 90	1206	33.3	265	50.0	48.5	47.0	.706

APPENDIX D

RAW DATA COLLECTED FOR NON-ATHLETES (pre-training)

NAME	AGE	WEIGHT (lb)	HEIGHT	HOURS SLEEP	LAST MEAL (hrs)	4.5 X 80 KPM / TIME	4.0 X 80 KPM / TIME	4.0 X 90 KPM / TIME	4.5 X 80 KPM / TIME		MEAN OF 2,3,4		LEG PUSH (lb)			
MIKE LAMB *	19	152	5'10"	5	5	1309	943	978	1065		995		360			
						36.1	29.3	27.0	29.4							
GARY LITTLE-TON +	19	153	5'8"	8.5	4	1178	1144	1049	1069		1087		320			
						32.5	35.5	29.0	29.5							
JIM MCGONI-GLE *	18	148	5'10"	6.5	1	1298	1086	1124	1061		1090		365			
						35.8	33.7	31.0	29.3							
TOM O' NEILL +	20	172	6'2"	8	17	1235	1188	1069	1489		1249		420			
						34.1	36.9	29.5	41.1							
RANDY VAN KUIKEN +	19	169	5'11"	7	18	1232	1034	1087	1330		1150		370			
						34.0	32.1	30.0	36.7							
BILL WHIT-MIRE *	18	158	6'2"	8	1.5	1450	1275	1445	1250		1323		330			
						40.0	39.6	39.9	34.5							
MIKE ZERBACH *	19	176	5'11"	7.5	18	1462	1110	1167	1178		1152		400			
						40.4	34.5	32.2	32.5							

* weight trainer + runner

APPENDIX D

RAW DATA COLLECTED FOR NON-ATHLETES (post-training)

NAME	AGE	WEIGHT (lb)	HEIGHT	HOURS SLEEP	LAST MEAL (hrs)	4.5 X 80 KPM / TIME	4.0 X 80 KPM / TIME	4.0 X 90 KPM / TIME	4.5 X 80 KPM / TIME		MEAN OF 2,3,4	CHANGE FROM PRE TEST	LEG PUSH (lb)	CHANGE FROM PRE-TEST		
MIKE LAMB *	19	149	5'10"	6.5	8	1124	1228	1178	1242		1216	I	390	I		
						31.0	33.9	32.5	34.3							
GARY LITTLE-TON +	19	153	5'8"	8.5	15	1365	1179	1463	1428		1357	I	305	D		
						37.7	36.6	40.4	39.4							
JIM MCGONI-GLE *	18	153	5'10"	6.5	1	1124	953	1011	1228		1064	SAME	400	I		
						31.0	29.6	27.9	33.9							
TOM O'NEILL +	20	171	6'2"	8	15	1504	1368	1330	1387		1362	I	425	SAME		
						41.5	42.5	36.7	38.3							
RANDY VAN KUIKEN +	19	170	5'11"	5	1.5	1267	1194	1060	1315		1190	SAME	360	D		
						35.0	37.1	29.3	36.3							
BILL WHIT-MIRE *	18	160	6'2"	8	2	1246	1125	1098	1369		1191	D	360	I		
						34.4	34.9	30.3	37.8							
MIKE ZERBACH *	19	179	5'11"	7.5	2	1348	1086	1178	1409		1224	I	460	I		
						37.2	33.7	32.5	38.9							

*weight trainers +runners

APPENDIX E

SAMPLE SHEET FOR GAS COLLECTION DATA

APPENDIX E

SAMPLE SHEET FOR GAS COLLECTION DATA

HUMAN PERFORMANCE LABORATORY

Subject_______________ Date_______________ Treatment_______________

Control Data: Rm Temp____ Bar Pr____ Rel Hum____ Oral Temp____

Bdy Wt____ Ht____ Resting Pulse____ ____ ____ ____ Bl Pr____

Last food____ Drink(not H_2O)____ Hrs Slp____ Last Ex____

Other ____

Experimental Data:

____

____

____

____

____

____

____

____

Ventilation: Gasometer factor (GF)________ Meter factor____________
Conversion factor (derived from bar pr and temp of gas) = CF

post		pre		dif						liters	
_____	-	_____	=	_____	x GF =	_____	X CF =	_____	/min. =	_____	VR (L/min)
_____		_____		_____		_____		_____		_____	
_____		_____		_____		_____		_____		_____	
_____		_____		_____		_____		_____		_____	

Gas Analysis:

	T1	T2	$\bar{X}$	RO	T-O_2		VR				ccO_2/min
CO_2	_____	_____	_____	_____	_____	x	_____	=	_____	/100 =	_____
O_2	_____	_____	_____	_____	_____		_____		_____		_____
	_____	_____	_____	_____	_____		_____		_____		_____
	_____	_____	_____	_____	_____		_____		_____		_____
	_____	_____	_____	_____	_____		_____		_____		_____
	_____	_____	_____	_____	_____		_____		_____		_____

APPENDIX F

SPEARMAN RANK ORDER CORRELATION AMONG SELECTED TESTS

APPENDIX F

SPEARMAN RANK ORDER CORRELATIONS AMONG SELECTED TESTS

TEST	1	2	3	4	5	6	7	8	9	10
1. KPM($\overline{X}$)			-.171	-.866	.471	.429	-.657	.486	-.286	-.200
2. $\frac{\text{KPM}(\overline{X})}{\text{B.W.}}$			-.486	-.543	.129	.257	-.143	.486	.029	.086
3. KPM(t)					.500	.200	-.429	.257	.200	.505
4. $\frac{\text{KPM(t)}}{\text{B.W.}}$					-.643	-.600	.886	-.371	.600	.486
5. LEG PUSH							-.614	.757	-.329	-.100
6. $\frac{\text{LEG PUSH}}{\text{B.W.}}$							-.429	.771	-.371	-.086
7. VERTICAL VELOCITY								.429	.600	.543
8. POWER									.257	.486
9. OXYGEN UTILIZATION										.943
10. OXYGEN DEBT										

APPENDIX G

SPEARMAN RANK ORDER CORRELATION FORMULA

APPENDIX G

SPEARMAN RANK ORDER CORRELATION FORMULA

$$RHO = 1 - \frac{6\sum D^2}{N(N^2 - 1)}$$

WHERE:

$\sum D^2$ is the sum of the squares of the differences between the ranks of the individuals on the two tests being measured.

N is the number of subjects in each group.

APPENDIX H

RAW DATA FOR PILOT STUDY

APPENDIX H

RAW DATA FOR PILOT STUDY

SUBJECT	DATE	LOAD X RATE	WORK PERFORMED (KPM's)	COMMENTS
T.H.	February 25	4.5 X 60	895	Pace too slow
	"	4.0 X 80	1028	Pace seemed good
T.H.	March 3	4.5 X 90	1069	Too difficult
	"	4.5 X 80	1449	
	"	4.0 X 90	1368	
T.H.	March 4	4.5 X 80	1287	
	"	4.0 X 80	1142	
	"	4.0 X 90	1184	
T.H.	March 5	4.5 X 80	1376	4.5 X 80 seems to be best combination
	"	4.0 X 80	1224	
		4.0 X 90	1341	
T.H.	March 6	4.5 X 80	1449	
	"	4.0 X 80	1234	
	"	4.0 X 90	1368	

APPENDIX H (continued)

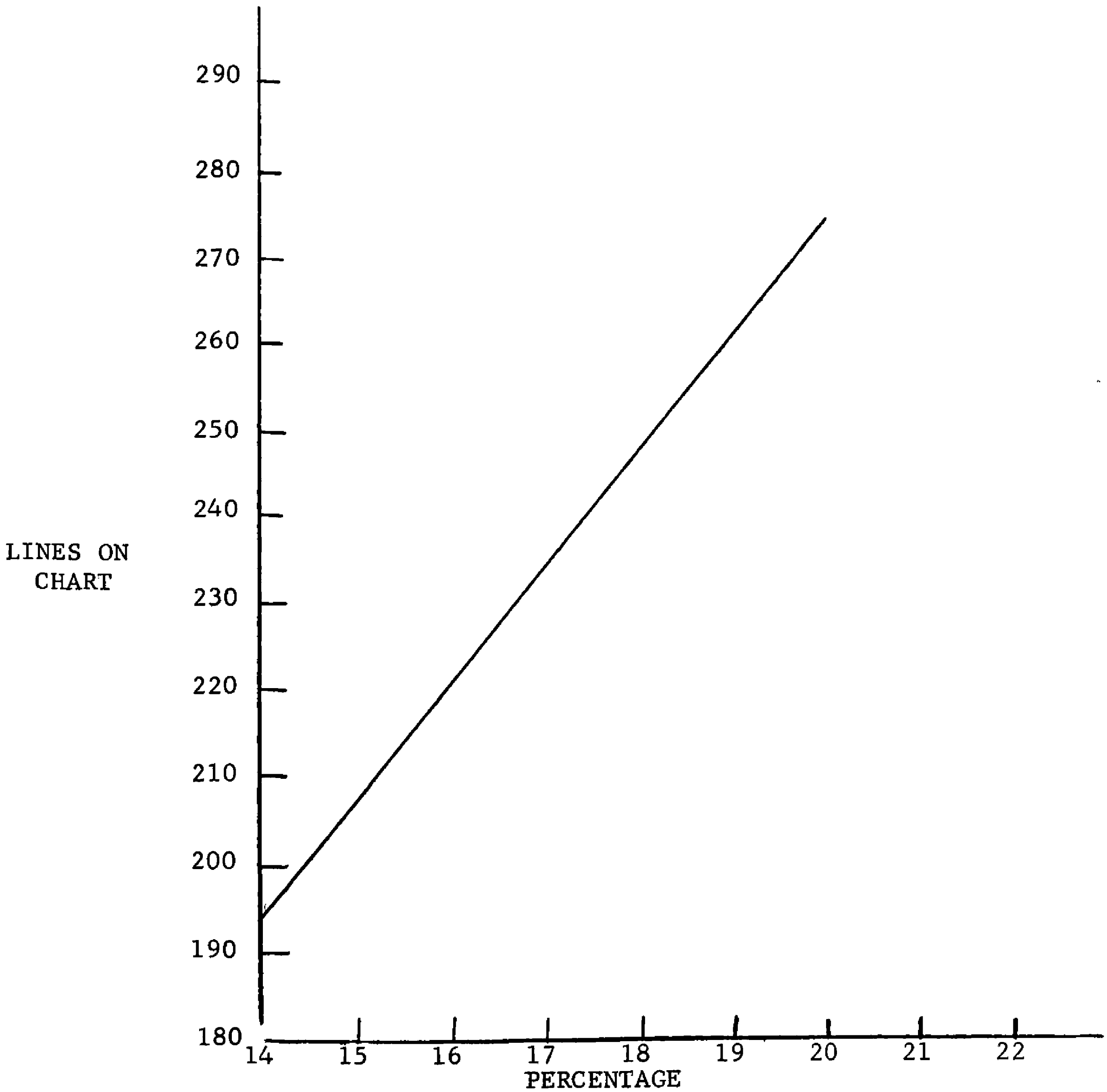
SUBJECT	DATE	LOAD X RATE	WORK PERFORMED (KPM's)	COMMENTS
V.C.	February 27	5.0 X 90	1653	Could not
	"	4.5 X 90	1671	maintain pace
V.C.	March 3	4.5 X 90	1540	
	"	4.5 X 80	1704	
	"	4.0 X 90	1632	
V.C.	March 4	4.5 X 90	1577	Very difficult
	"	4.5 X 80	1680	to keep pace
	"	4.0 X 90	1633	at 4.5 X 90
V.C.	March 5	4.5 X 90	1536	4.5 X 80 and
	"	4.5 X 80	1709	4.0 X 90 were
	"	4.0 X 90	1688	most consistent

APPENDIX I

SAMPLE GRAPHS FOR GAS ANALYSIS

APPENDIX I

GRAPH FOR OXYGEN EXAMINATION



APPENDIX I

GRAPH FOR CARBON DIOXIDE EXAMINATION