A SUGGESTED PROCEDURE FOR MEASURING
MAXIMAL OXYGEN DEBT

By

MELVIN GENE WRIGHT

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
1957

Master of Science in Physical Education
Baylor University
Waco, Texas
1959

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF EDUCATION
May, 1972

A SUGGESTED PROCEDURE FOR MEASURING

MAXIMAL OXYGEN DEBT

Thesis Approved:

Aix B. Harrison
Thesis Adviser

John G. Bayless

Robert E. Mangum

Albin P. Warner

Robert T. Alciatore

D. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

The investigator is sincerely thankful for Dr. Aix Barnard Harrison, Professor, Health, Physical Education and Recreation, for his willingness to be of assistance and guidance, for his outstanding ability to communicate supportiveness, and his never-ending patience. For these, and other countless ways in which he imparted his wisdom, the author is eternally grateful.

Recognition and sincere appreciation are also extended to other members of the committee for their cooperation and encouragement. They are Dr. Albin Warner, Head, Health, Physical Education and Recreation; Dr. John Bayless, Associate Professor, Health, Physical Education and Recreation; Dr. Robert Alciatore, Professor of Education; and Dr. Robert Mangum, Associate Professor of Education.

Finally, I would like to express appreciation to my wife, Althea, and our children, Melanie and Lane, whose understanding, encouragement, and sacrifice were instrumental in the preparation of this dissertation.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

There are basically two types of muscular work discussed by physiological researchers today. These are aerobic (with oxygen) and anaerobic (without oxygen).

In aerobic work the subject can take in enough oxygen to meet the work requirements and thus sustain the pace for a long period of time. This type of work has also been described as steady state work. This means that the body can take in the oxygen that it needs while performing the work load. The body generally meets its oxygen needs in this way. Aerobic work was extensively researched by Dr. Kenneth Cooper and reported in his book entitled Aerobics.[1] It was found that the heart rate during aerobic work usually remains below 180 beats per minute. Continued participation in aerobic work increases oxygen consumption by increasing the efficiency of the means of supply and delivery. In other words, aerobic work improves the overall condition of the body, especially its most important parts, the lungs, heart, blood vessels and the body tissue.

In anaerobic work the heart rate is always up above 180 beats per minute, and the work load is so intense that the subject can maintain the pace for only a short period of time. It is during this emergency

---

[1] Kenneth H. Cooper, Aerobics, Bantam Books, Inc. (New York, 1968).

type of physical exercise that oxygen debt occurs.

An adequate supply of oxygen is necessary for normal life and activity. It is used by all the cells for oxidative processes in the metabolic changes from which energy is derived. Whenever more energy is required, metabolism is increased, and hence, the need for oxygen is also increased. It is important to realize that man practically lives a hand-to-mouth existence as far as his oxygen supply is concerned. There is, however, a certain amount of oxygen present in the body which can be used in emergency. This oxygen is found in the blood and in the lungs.[2]

The muscles do have the ability to work temporarily without oxygen. To understand this we must realize that man gets his energy from the food he eats. We must also understand how this energy is used to perform the mechanical work of muscular contraction. The energy liberated during the breakdown of food is not directly used to do work. Rather it is employed to manufacture another chemical compound called adenosine triphosphate or, more simply, ATP, which is stored in large quantities in all muscle cells. Only from the energy released by the breakdown of this compound can the cell perform its specialized work.[3]

The structure of ATP consists of one very complex component, adenosine, and three less complicated parts called phosphorus groups. For the purposes of this discussion, its chemical importance lies in the phosphate groups. When one of these phosphate bonds is broken, at

---

[2]Peter V. Karpovich, Physiology of Muscular Activity, W. B. Saunders Company (Philadelphia, 1965), p. 55.

[3]Donald K. Matthews, E. L. Fox, The Physiological Basis of Physical Education and Athletics, W. B. Saunders Company (Philadelphia, 1971), p. 8.

least 7,000 calories of energy are liberated and adenosine diphosphate (ADP) plus free phosphate (Pi) are formed. This energy released during the breakdown of ATP represents the immediate source of energy that can be used by the muscle cell to perform its work.

Because ATP is the immediate source of energy for muscle contraction, an explanation of its source is needed. There are three systems that supply ATP, but the one known as the ATP-PC system is the most important to this discussion. It involves the breakdown of only one compound, phosphocreatine (PC). Phosphocreatine, like ATP, is stored in large quantities in muscle cells. It is also similar to ATP in that when its phosphate group is removed, a large amount of energy is liberated. The end products of this are creatine and free phosphate. This energy is immediately available and is used directly to resynthesize ATP. For example, as rapidly as ATP is broken down during muscular contraction, it is continuously re-formed from ADP and Pi by the energy liberated during the breakdown of the stored PC.[4]

The importance of the ATP-PC system to physical education and athletics is exemplified by the powerful quick starts of sprinters, football players, high jumpers, and shot-putters, and by similar feats that require a few seconds to complete (running all-out up a flight of stairs). This system is not dependent upon a series of reactions nor on the oxygen we breathe and for this reason it represents the most rapid available source of ATP for use by the muscle.[5]

The second of the three systems deals with lactacid. The

---

[4]Ibid., p. 9.

[5]Ibid., p. 26.

significance of the lactacid oxygen debt as related to exercise performance lies in the amount of lactic acid that can be accumulated during maximal effort. The maximum amount of energy obtainable from the lactacid mechanism is about twice that of the alactacid or ATP-PC system. However, to obtain a comparable amount of energy from this lactacid mechanism requires a longer period of time and, therefore, supplies only about half as much power as the ATP-PC system. During exercise the function of this mechanism is to sustain maximal effort after the ATP-PC system is exhausted. For example, champion athletes can run 100, 200, and 400 meters in 10.2, 20.5, and 45.2 seconds, respectively. The ATP-PC system is probably exhausted at the end of 100 meters, yet each 100 meters of the 200- and 400-meter events is run at about the same speed.[6]

Oxygen debt is a term that was coined by A. V. Hill in 1927. It is defined as the quantity of oxygen required by the contracting muscles over and above the quantity actually supplied to them during their activity.[7] The debt is represented by an elevated oxygen consumption during the period of recovery from physical effort. This elevated rate during recovery reflects a deficit incurred during the performance of the task. The oxygen debt reflects this discrepancy between the oxygen requirement of the task and the oxygen uptake during the performance of the task.

Through the research of Hill, Margaria, and other early leaders, a concept of two separate stages of oxygen debt was established, an

---

[6]Ibid., p. 26.

[7]Benjamin Ricci, Physiological Basis of Human Performance. Lea and Febiger (Philadelphia, 1967).

alactacid stage and a lactic acid stage.

Light to moderate work loads are performed during the alactacid stage of oxygen debt, and steady state is maintained during this period. The alactacid debt occurs at the initial phase of work with oxygen debts of up to two and one-half liters per minute, while heart rates were not elevated higher than 160 beats per minute. The stage is accompanied by increases of lactic acid in the muscle tissue, but not in the blood stream, and the debt is quickly repaid, generally within three to five minutes.

During the lactic acid stage of oxygen debt, there is an accumulation of excessive lactic acid in the blood stream and this is linearly related to the amount of work performed. Heart rates are elevated to above 180 beats per minute and the removal of excessive lactic acid during recovery is much slower, taking from 15 to 90 minutes.

The calculation of maximum oxygen debt may appear to be a simple matter to the casual observer. However, large differences exist between maximum theoretical values for the oxygen debt following muscular exercise (three-five liters) and some experimentally determined values (12-20 liters).[8] The wide range of maximal oxygen debts that have been reported is a major concern. Values ranging from 12-20 liters have been reported for human subjects, but Margaria et al., in a detailed kinetic analysis, have indicated that the maximum value for

[8] H. Welch, J. Faulkner, J. Barclay, and G. Brooks, "Ventilatory Response During Recovery From Muscular Work and Its Relation to Oxygen Debt," Medicine and Science in Sports, Vol. 2, No. 1 (1970), pp. 15-19.

the oxygen debt should be only about four liters.[9] This value is supported by experiments on dog skeletal muscle. The largest debts in the animal experiments were equivalent to four or five liter oxygen debt in a 70 kg. man.

> At face value, the calculation of oxygen debt appears to be a simple procedure: one need merely total the net recovery oxygen. Yet, most interesting, and confusing, is the wide variation in maximum oxygen debt values. Karpovich dubiously noted a 22.8 liter oxygen debt which had been reported by Krestovnikoff. Winton and Bayliss report that from 15 to 20 liter debts may be incurred. Margaria defends, biochemically, a maximum debt of approximately eight liters. Such wide variation in oxygen debt values suggests errors in method of measurement. Generally higher debts will be incurred after all-out effort of short duration.[10]

Calculating the oxygen debt leaves much room for variation and error since recovery may have many meanings. Recovery values within 50 ml. of resting values may be accepted by some as evidence of complete recovery. Other researchers may establish a 25 ml. variation before adjudging recovery to be complete. If the post-work oxygen consumption values remain elevated for many hours, the oxygen debt calculated would greatly increase.[11]

We know that during vigorous exercise, the blood circulation quickens, blood and lymph stream through the muscles supplying the cells with oxygen and nutrition and removing waste products. The heart's activity is accelerated, exercising and strengthening its own fibers, while it is pumping the blood. The work of all muscles

---

[9] R. Margaria, P. Aghemo, and E. Rovelli, "Measurement of Muscular Power (Anaerobic) in Man," Journal of Applied Physiology, Vol. 2 (1966), pp. 1662-1664.

[10] Benjamin Ricci, p. 182.

[11] Ibid., p. 183.

is affected by the efficiency of the heart. If a muscle does its job well, the quality of its contractions must be improved through such factors as: fuel being made available in greater amount because of improved circulation of blood through the muscle; better coordination of the individual muscle fibers and more complete use of all muscle fibers. Therefore, it is easy to see that the cardiovascular system performs a vital service in the performance of sustained muscular activity.[12] This is especially true when the exercise is vigorous enough to cause an individual to reach his maximum oxygen debt. It is not only dependent upon the strength of the muscles involved in the activity but must rely greatly on the effective functioning of the circulatory system.[13]

Johnson, Brouha, and Darling feel that whatever exercise is used to assess work capacity, the exercise must put the cardiovascular system under considerable stress. The work should be of such intensity that about one-third of all subjects stop from exhaustion within five minutes.[14]

The methods known for assessing or evaluating physical efficiency may be classified as field or laboratory tests. Nagle, Naughton, and Balke believe that physical fitness is most accurately assessed in the laboratory by making physiological measurements on a motor-driven

---

[12]H. Harrison Clarke, Application of Measurement to Health and Physical Education, Prentice-Hall, Inc., (Englewood Cliffs, 1967), p. 179.

[13]Ibid., p. 183.

[14]R. E. Johnson, L. Brouha, and R. C. Darling, "A Test of Physical Fitness for Strenuous Exertion," Rev. Canad. Biol., 1 (June, 1942), p. 8.

treadmill or riding a stationary bicycle ergometer.[15]

Most of the tests being used today are aerobic or a combination of aerobic and anaerobic. The most widely used tests are: 1) Balke's Treadmill Test, 2) Balke and Cooper's Fifteen and Twelve Minute Running Tests, 3) Astrand's Bicycle Ergometer Test, and 4) Step Tests (Harvard Step Test and Tuttle Pulse-Ratio). The general public is most concerned with this type of testing because it is an evaluation of an individual's ability to function in normal day to day living.

This study is concerned with an anaerobic test that will push the individual to complete exhaustion and to his maximal oxygen debt capacity. The oxygen debt test is the only way we have of measuring an individual's ability to perform under very strenuous emergency type conditions. There has been no widespread demand for a test of maximal oxygen debt in the past, and as a result, very few have been developed. For example, there have been only two field tests reported in the literature to date. Both of these tests involved the subjects running up a short flight of stairs. Margaria[16] developed a test in 1966, and Costill[17] and his associates followed with a similar test in 1969.

The main method of examining maximal oxygen debt capacity of an individual has therefore been by laboratory procedures. There have been two paramount problems facing researchers that have been doing

---

[15] F. J. Nagle, B. Balke, and J. P. Naughton, "Gradational Step Tests for Assessing Work Capacity," Journal of Applied Physiology (July, 1965), p. 745.

[16] R. Margaria, P. Aghemo, and E. Rovelli, pp. 1662-1664.

[17] D. Costill, W. Hoffman, P. Kehoe, S. J. Miller, and W. C. Meyers, "Maximum Anaerobic Power Among College Football Players," Journal of Sports Medicine, Vol. 8 (1969), pp. 103-106.

maximal oxygen debt work in laboratories. The first problem has been that there is no uniform method for eliciting maximal oxygen debt. Hermansen[18] described the second obstacle when he stated that the range of variability of anaerobic work has not been determined because there has been no accepted test procedure to measure this capacity. Because the measuring of oxygen debt capacity is so important in evaluating an individual's ability to perform strenuous exercise, the purpose of this study was to develop and evaluate a procedure to both elicit and measure maximal oxygen debt.

Statement of the Problem

The purpose of this study was to develop and evaluate a procedure for eliciting and measuring maximal oxygen debt.

Sub-Problems of the Study

The sub-problems of the study were:

1) To determine a treadmill test procedure which can uniformly be expected to elicit a maximal oxygen debt.
2) To determine reliability of this test procedure.
3) To determine the relationship between maximal oxygen debt as measured by recovery of oxygen intake to within ten per cent of the resting baseline and any one of several recovery variables which might occur before this baseline is reached. Specifically, these variables are oxygen intake at levels of 15 and 20 per cent above resting, heart rate levels at 10, 15, and 20 per cent above

---

[18] L. Hermansen, "Anaerobic Energy Release," Medicine and Science in Sports, Vol. I (1969), pp. 32-38.

resting, carbon dioxide production and respiratory quotient.

Limitations of the Study

1) Although verbal encouragement and monetary rewards were initiated by the researcher, the motivation factor was somewhat of a problem.
2) Orientation of subjects to the equipment and testing procedures preceded the test administration, but this was not successful in relieving completely the testing apprehension in the subjects.
3) Environmental factors such as eating and sleeping were not regulated.
4) All subjects were volunteers and not randomly selected.

Delimitations

The subjects in this study were limited to male physical education majors and minors at Oklahoma State University.

Assumptions

1) It was assumed that all subjects were in good medical condition because they were accepted as physical education majors and minors at Oklahoma State University.
2) The subjects exerted a maximum effort in performing the required tests.
3) The verbal encouragement that was initiated by the researcher had the same motivational effect on all subjects.
4) Skill factors would not significantly effect test results because of the nature of the test which required only the skills of running and breathing.

5) It was assumed that logical validity could be used because the test was an oxygen debt test.

Significance of the Study

In a recent article, Welch expressed concern over the great variation in the estimates of the maximum oxygen debt.[19] For example, a range from 12 to 20 liters is common in research reports,[20, 21] but detailed kinetic analysis suggest that the maximum value for oxygen should be no more than four liters.[22]

A. V. Hill, in a 1924 research report, declared that oxygen debt was an extremely beneficial measure of the energy levels derived during muscular work.[23] However, as Welch points out, the great variation in estimates of the maximum oxygen debt challenges the utility of the concept.

Despite attempts to arrive at a uniform method for determining oxygen debt, none has yet to be established which is universally

---

[19] Hugh G. Welch, John A. Faulkner, Jack K. Barclay, and George Brooks, "Ventilatory Responses During Recovery From Muscular Work and Its Relation With Oxygen Debt," Medicine and Science in Sports, Vol. 2 (Spring, 1970), p. 15.

[20] A. V. Hill, C. H. Long, and H. Lupton, "Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen," Medicine and Science in Sports, Vol. 2, No. 1 (1970), p. 15.

[21] S. Robinson, D. L. Robinson, R. J. Mountjoy, and R. W. Bullard, "Influence of Fatigue on the Efficiency of Men During Exhaustive Runs," Journal of Applied Physiology, Vol. 12 (March, 1958), p. 197.

[22] R. Margaria, P. Cerretelli, R. E. DiPrompero, C. Massari, and G. Torelli, "Kinetics and Mechanism of Oxygen Debt Contraction in Man," Journal of Applied Physiology, Vol. 18 (1963), p. 372.

[23] Hugh G. Welch, John A. Faulkner, Jack K. Barclay, and George A. Brooks, p. 15.

acceptable. The research in this area presents a vast number of methods for doing oxygen debt experiments, but even the variations in baselines are so great and the period of recovery so variable (12 minutes[24] to two hours[25]) that they are nearly useless.

Hermansen[26] states in his article on anaerobic energy release that the range of variability of anaerobic work has not been determined because there has been no accepted test procedure to measure this capacity.

Therefore, a uniform procedure for determining the oxygen debt capacity is indeed necessary before research in this important physiological area can be meaningfully interpreted.

Definition of Physiological Terms

1) Aerobic Capacity - It is the maximal amount of oxygen an individual can consume per minute for extended time periods.

2) Anaerobic Capacity - It is the maximal amount of muscular work an individual can perform without oxygen. It is measured by the excess oxygen that is consumed during a recovery period over the normal resting oxygen intake.

3) Oxygen Debt - A deficit in oxygen intake during any activity that must be repaid during a recovery period.

4) Maximum Oxygen Debt - The largest amount of oxygen debt an

---

[24] David A. Cunningham and John A. Faulkner, "The Effect of Training on Aerobic and Anaerobic Metabolism During Short Exhaustive Runs," Medicine and Science in Sports, Vol. I (June 1, 1969), p. 65.

[25] Robinson et al., p. 372.

[26] L. Hermansen, "Anaerobic Energy Release," Medicine and Science in Sports, Vol. I (1969), pp. 32-38.

individual can accumulate as a result of some all-out exercise such as the treadmill run. Maximum oxygen debt for this study has been determined after the completion of the all-out run by measuring oxygen consumed until the subject reached "ten per cent" above his resting oxygen consumption.

5) EKG - Electrocardiograph or record of the electrical potential of the heart.

6) Respiratory Quotient (R.Q.) - The ratio of the carbon dioxide output to oxygen consumed.

Description of Instruments

1) Large Two-Way Breathing Valve - A Device which enabled the subjects to take in atmospheric air and then to expire the air into a tissot tank for measurement of maximal breathing capacity. (Model - Triple "J" Valve; Warren E. Collins, Inc., 220 Wood Road, Baintree, Mass.)

2) Physiograph - An apparatus that was used to monitor and record heart rate during work and recovery. (Type PMP-4A-Four Channels; E & M Instrument Co., Inc., Houston, Texas.)

3) Quinton Motorized Treadmill - An apparatus with a continuously moving belt which could be made to run at various speeds and inclinations, thus standardizing work loads. (Model 642; Speed Range 1.5-25 miles per hour; Elevation (per cent grade) 0-40; Seattle, Washington.)

4) Telemetry - A unit that sent a signal by radio waves (no wires) from a small transmitter which was attached to the subject to a receiver from which the signal was recorded on the physiograph.

(Model F.M. 1100-7; E & M Instrument Co., Inc., Houston, Texas.)

5) Tissot Tank - A large stainless steel tank which was used for collecting volumes of expired air during rest and work. [Warren E. Collins, Inc., 555 Huntington Ave., Boston 15, Mass.; Capacity-120 liters (0 mm - 720 mm); Serial No. 1440.]

6) Transmitter and Electrodes - Equipment that transmitted heart sounds by radio waves into the telemetry apparatus. (Model F.M.-1100-E2, Part No. 98-100-71; E & M Instrument Co., Inc., Houston, Texas.)

7) Douglas Bag - (Hydro Tex Corp., Chicago, Ill.) Plastic bags with capacity of from 100-400 liters that were used to collect expired air during recovery.

8) Pulmo-Analyzer - (Godart Instrumentation Association, New York, N.Y.) An instrument used to analyze the percentage of oxygen and carbon dioxide in samples of expired air.

9) Nose Clip - A device used to clamp the nostrils shut.

10) All-Out Run - The subject running until complete exhaustion.

Summary

There are basically two types of muscular work discussed by physiological researchers today. These are aerobic (with oxygen) and anaerobic (without oxygen). In aerobic work the subject can take in enough oxygen to meet the work requirements and thus sustain the pace for a long period of time. It was found that the heart rate during aerobic work usually remains below 180 bpm. In anaerobic work the heart rate is always up above 180 bpm, and the work load is so intense that the subject can maintain the pace for only a short period of time.

It is during this emergency type of physical exercise that oxygen debt occurs.

Oxygen debt is a term that was coined by A. V. Hill in 1927. It is defined as the quantity of oxygen required by the contracting muscles over and above the quantity actually supplied to them during their activity. The debt is represented by an elevated oxygen consumption during the period of recovery from physical effort. There are two separate stages of oxygen debt, an alactacid stage and a lactic acid stage. Light to moderate work loads are performed during the alactacid stage of oxygen debt, with heart rates no higher than 160 bpm. The stage is accompanied by increases of lactic acid in the muscle tissue, but not in the blood stream, and the debt is generally repaid within three to five minutes. During the lactic acid stage of oxygen debt, there is an accumulation of excessive lactic acid in the blood stream. Heart rates are elevated to above 180 bpm, and recovery is much slower, taking from 15 to 90 minutes.

The wide range of maximal oxygen debts that have been reported is a major concern. Values ranging from 12-20 liters have been reported for human subjects. Such wide variation in oxygen debt values suggests errors in the method of measurement. Calculating the oxygen debt leaves much room for variation and error since recovery may have many meanings. Researchers have used different baselines to determine when recovery was completed, and therefore have reported wide variations in debt repayments.

This study is concerned with an anaerobic test that will push the individual to complete exhaustion and to his maximal oxygen debt capacity. There have been two paramount problems facing researchers in doing maximal oxygen debt work. The first problem has been that there is no uniform method for eliciting maximal oxygen debt. The second obstacle is that the range of variability of anaerobic work has not been determined because there has been no accepted test procedure to measure this capacity. Because the measuring of oxygen debt capacity is so important in evaluating an individual's ability to perform strenuous exercise, the purpose of this study was to develop and evaluate a procedure to both elicit and measure maximal oxygen debt.

CHAPTER II

REVIEW OF RELATED LITERATURE

Studies Discussing the Relationship of Lactic Acid

In 1923, A. V. Hill introduced the term "Oxygen Debt," and many researchers have been working since that time to prove or discount the importance of oxygen debt in assessing work capacity.

A. V. Hill and H. Lupton were two of the first pioneers in the study of oxygen debt and the accumulation of lactic acid in the muscles. In one of their earliest studies they discussed the following important concepts.[1]

Lactic acid is a very important ingredient in the economy of the muscle. Its oxidation provides the power required to do external work, and it appears to be derived from the glycogen stored. When a man's muscles are exercised at a constant speed, the lactic acid content of the active muscle increases gradually from its resting minimum. The rise in lactic acid content increases the rate of oxidation, and if the oxygen supply is adequate, a steady state is reached in which the rate of lactic acid production is balanced by the rate of its oxidative removal. Therefore, its concentration remains constant in the muscle

[1] A. V. Hill and H. Lupton, "Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen," The Quarterly Journal of Medicine, Vol. 16 (1923), pp. 135-171.

as long as exercise at that speed is maintained. If the severity of the exercise becomes too great, the supply of oxygen cannot cope with the production of lactic acid, and exhaustion rapidly sets in. It is under these conditions that oxygen debt occurs.

Harvard and Reaz conducted an experiment on the influence of exercise on the inorganic phosphates of the blood and urine in man.[2] The exercise consisted of the subject running vigorously up and down the laboratory stairs until he was exhausted. At various times during the experiment samples of blood were taken and the inorganic phosphate content of the whole blood was analyzed. The results indicated that after short vigorous exercise the inorganic phosphate in blood first rises a little above, then falls considerably below, the normal value in man. The men that were in athletic training did not fall as far below normal as untrained subjects. The authors concluded that the changes observed in blood phosphate were due mainly to changes in the lactacidogen content of the muscle.

The purpose of an experiment by Fletcher and Hopkins[3] was to examine the effect of an abundant supply of oxygen upon the development of lactic acid in surviving exercised muscle, and upon the stability of the acid within the muscle after its formation.

This experiment made it clear that the exercised muscle, when exposed to a sufficient supply of oxygen, has in itself the power of dealing in some way with lactic acid which has accumulated during

---

[2]R. E. Harvard and G. A. Reaz, "The Influence of Exercise on the Inorganic Phosphates of the Blood and Urine," Journal of Physiology, Vol. 61 (1926), pp. 35-48.

[3]W. M. Fletcher and F. G. Hopkins, "Lactic Acid in Amphibian Muscle," Journal of Physiology, Vol. 35 (1907), pp. 247-309.

fatigue. While the fibers are recovering from fatigue and regaining irritability in an atmosphere of pure oxygen, their content of lactic acid was greatly reduced.

An experiment to investigate the production and removal of lactic acid, the amount and payment of oxygen debt in man was conducted by Margaria, Edwards, and Dill.[4] They summarized their findings as follows:

1. The removal of lactic acid from the blood during recovery is an exponential function of time, its speed of disappearance is proportional to the concentration of the lactic acid at that moment.

2. No extra lactic acid appears in the blood up to a rate of work corresponding to about two-thirds of the maximum metabolic rate, after which the lactic acid increases very rapidly.

3. The removal of lactic acid in the body is a very slow process, only one-half is removed in fifteen minutes.

4. The alactacid oxygen debt is approximately a linear function of the oxygen intake in exercise. It is supposed to be related to the oxidation of substances (ordinary fuel) furnishing the energy for the resynthesis of phosphogen split down during muscular contraction.

5. The lactacid oxygen debt starts coming into play only when there may be reasons to believe that the work is carried on in anaerobic condition. Its amount, relatively to the total amount of oxygen debt, increases particularly rapidly at the maximum rates of work.

6. The speed of payment of the alactacid oxygen debt and the speed of disappearance of lactic acid from the blood vary with the oxygen tension in the inspired air.

7. The disappearance of lactic acid from the blood at the beginning of recovery after strenuous exercise shows a lag which does not seem to be fully explained either by delay in the diffusion of lactic acid from muscles to

[4] R. Margaria, H. T. Edwards, and D. B. Dill, "The Possible Mechanisms of Contracting and Paying the Oxygen Debt and the Role of Lactic Acid in Muscular Contraction," American Journal of Physiology, Vol. 106 (1933), pp. 689-715.

the blood or by a slower oxidation of lactic acid, or by a delayed lactic acid production.[5]

Margaria and Edwards[6] in a later study looked at the variation of the total amount of lactic acid in the body during recovery from muscular work. The following conclusions were made:

1. The lactic acid concentration in the blood may be taken as proportional to the total amount of lactic acid in the body.

2. At the beginning of recovery, at the time when a rapid payment of oxygen debt occurs, no corresponding rapid removal of lactic acid is observed, thus confirming that this fraction of the oxygen debt is not related to the lactic acid mechanism.

3. A delay in the removal of lactic acid, which lasts three to four minutes after the end of a five-minute period of exercise to exhaustion was observed.

4. The speed of removal of lactic acid during recovery appears to be higher the smaller the amount of lactic acid produced during exercise.[7]

In another study Margaria and Edwards[8] did an experiment which consisted of two short and strenuous runs with a five-minute rest period in between. The subject exhausted his alactacid mechanisms for contracting oxygen debt during the first run. The second run was performed nearly exclusively at the expense of the lactacid mechanism. In this way the existence of the alactacid mechanism for contracting oxygen debt could be detected, and its relative importance evaluated.

---

[5]Ibid., p. 715.

[6]R. Margaria and H. T. Edwards, "The Removal of Lactic Acid From the Body During Recovery From Muscular Exercise," American Journal of Physiology, Vol. 107 (1934), pp. 681-686.

[7]R. Margaria et al., (1934), p. 686.

[8]R. Margaria and H. T. Edwards, "The Sources of Energy in Muscular Work Performed in Anaerobic Conditions," American Journal of Physiology, Vol. 108 (1934), pp. 340-348.

The authors summarized the findings as follows:

1. The increase in lactic acid concentration in the blood following muscular work performed in anaerobic conditions was a linear function of the amount of work.

2. The amount of work performed anaerobically was considered to be proportional to the oxygen debt.

3. The fact that this relation is linear suggests that the breakdown of glycogen into lactic acid was really one of the mechanisms for contracting on oxygen debt, and therefore for performing work anaerobically.

4. The amount of work performed at the expense of the alactacid mechanism was about half the amount of work attributable to the lactacid mechanism.[9]

Dill, Edwards, Newman, and Margaria[10] did a study to analyze recovery from anaerobic work. The exercise was performed on a treadmill, and data were collected during recovery for a period of 90 minutes at intervals of ten minutes. The exercise period was very short with a range from only five seconds to 96 seconds. The following conclusions were reached:

1. The work was largely anaerobic, requiring the accumulation of an oxygen debt whose magnitude was an approximate function of time.

2. The removal rate was a logarithmic function of time, varying from time to time and from one person to another.

3. The lactic acid accumulated in this type of activity was proportional to the duration of the work.

4. The excess respiratory quotient (RQ) is expressed as a ratio of carbon dioxide produced to oxygen consumed for the entire process of work and recovery probably within the range of 0.9 to 1.0.[11]

---

[9]R. Margaria et al., (1934), pp. 299-307.

[10]D. B. Dill, H. T. Edwards, E. U. Newman, and R. Margaria, "Analysis of Recovery From Anaerobic Work," Arbeitsphysiologie, Vol. 9 (1934), pp. 299-307.

[11]D. B. Dill et al., Vol. 9 (1937), p. 307.

Block and his associates[12] conducted an experiment to determine the lactic acid in the blood of resting man. They found that lactic acid concentration in the blood of a resting man was not related simply to shifts in hydrogen concentration. They also found that of the total lactic acid found in the blood under resting conditions, only a part may originate from muscle activity. The authors concluded that no definite evidence is at hand to indicate the source of the remaining lactic acid, but they suggested that it may be a split product of carbohydrate mobilized for the maintenance of the general metabolism of the body.

Lactic acid was determined in muscle and blood obtained simultaneously from rats in rest or after exercise in an experiment by Newman.[13] At the end of all grades of exercise the lactic acid concentration in blood and muscle were approximately equal. Thus in the intact, exercising animal there was great and rapid diffusion of lactate between blood and muscle. The assumption that lactic acid in blood reflects its concentration in muscle was approximately true under these experimental conditions.

The Effects of Training on Oxygen Debt

There are studies that indicate that while an individual's anaerobic capacity is largely inherited, it is also trainable. Therefore, the effect of training on anaerobic performance would be of interest to

---

[12] A. U. Block, D. B. Dill, and H. T. Edwards, "Lactic Acid in the Blood of Resting Man," Journal of Clinical Investigation, Vol. 11 (1932), pp. 775-788.

[13] E. U. Newman, "Distribution of Lactic Acid Between Blood Muscle of Rats," American Journal of Physiology, Vol. 122 (1938), pp. 349-366.

physical educators, coaches, and athletes who are involved with work that produces oxygen debt. The following studies indicate that anaerobic capacity can be increased through training.

Robinson designed a study to see how metabolic adaptations would be affected by training. He used nine previously untrained college men and trained them for middle distance running for a period of 28 weeks.[14] Timed races on the track were held each week and showed consistent improvement in the running ability of the men. The subjects also ran on the treadmill at an exhausting pace for three to five minutes duration. This was repeated at intervals of two to three weeks during the training period. The results indicated that the average maximal oxygen consumption increased gradually and blood lactic acid increased gradually at the completion of training.

In another study related to training effects, Robinson and Harmon[15] tried to determine the results of training upon the lactic acid mechanism in work. The training consisted of a supervised running program with four workouts per week on the track. The subjects were tested in the laboratory before training started and at regular intervals during the training period on the treadmill. During the training period each time a subject was able to complete five minutes of the exhausting run the grade or speed or both were increased for the next testing period. An attempt was made to keep the work severe enough to exhaust him in

---

[14] S. Robinson, "Metabolic Adaptations to Exhausting Work as Affected by Training," American Journal of Physiology, Vol. 133 (1941), pp. 428-429.

[15] S. Robinson and P. M. Harmon, "The Lactic Acid Mechanism in Relation to Training," American Journal of Physiology, Vol. 132 (1941), pp. 757-769.

four to five minutes. The results indicated that the ability to accumulate lactic acid during anaerobic work increased with training.

Cureton developed a treadmill test to study the physical fitness of champion athletes.[16] The test consisted of an all-out run on the treadmill at ten miles an hour and a grade of 8.6 per cent. The average net oxygen debt of the champion athletes was 7.23 liters and a comparative sample of young men averaged 7.37 liters. The difference was not significant and Cureton concluded that oxygen debt was not a good organic test. He felt there was no way to tell the extent that "willpower" determines the results, but it appeared that the non-champions tried just as hard as the champions if oxygen debt was a measure of the distress that they were willing to tolerate.

Efficiency in performance depends upon the oxygen supply and utilization, but it also depends upon the efficiency of "buffering." In this process the lactic acid produced by the working muscles was neutralized in part by alkaline buffers (sodium bicarbonate, hemoglobin, phosphocreatine) and part was reconverted to glycogen. This buffering was facilitated by oxygen and, if there was insufficient oxygen available to oxidize the lactic acid and to facilitate the reconversion, the lactic acid accumulates.

Cureton further commented on the following important aspects of oxygen debt. In a "steady state" exercise the oxygen debt was negligible, but in an "all-out" maximal run to exhaustion the conditions are very different. Efficiency (defined as the ease with which the work is continued) was inversely related to the feelings of oxygen

---

[16]Thomas K. Cureton, Physical Fitness of Champion Athletes, (The University of Illinois Press, Urbana, 1951), pp. 314-350.

deficiency or carbon dioxide concentration during the run. When these conditions mount, the feelings of internal stress become unbearable. A highly trained runner was able to keep the oxygen deficiency or carbon dioxide concentration from mounting very fast and thus postpone the very distressful feelings and run longer. Finally, at the end of a longer run the distress mounts in the trained runner just the same, as in an untrained runner, but the trained runner could run for a longer time.

In conclusion, Cureton stated that oxygen debt was not related in a single manner to all-out running time. He gave three extraneous factors which interfere with the relationship of performance. The factors were listed in the following order:

1. Skill in running (not tensing up, proper balance, good stride).
2. Will power.
3. Physical build, especially strength.[17]

Pauline Hodgson[18] studied the effects of metabolism on participation in basketball. The results indicated that oxygen debt, expressed in liters per kilogram of body weight, varied from .025 to .86. The return of the rate of oxygen consumption to within five per cent of the pre-exercise level required from 15 to over 60 minutes.

The oxygen intake during exercise and recovery was determined for

---

[17]Thomas K. Cureton, (1951), p. 332.

[18]Pauline Hodgson, "Studies in the Physiology of Activity: III. On Certain Reaction of College Women Following Participation in Three-Count Basketball," Research Quarterly, Vol. 24 (1953), pp. 102-111.

subjects working on a bicycle ergometer in an experiment by Henry.[19] His results were in agreement with Hill[20] and Margaria's[21] theoretical position that the so-called alactic oxygen is probably not due to the lag of the 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. This production is in direct linear proportion to the work done by the muscles and is not characteristic of the individual. Robinson and his associates[22] conducted a study to determine the oxygen requirement in runners at different periods of exhausting runs at constant speed and the effects of varying the pace of exhausting runs of fixed distances. The data indicated that in order to run a given middle distance race in minimum time, the runner should follow a pace which would delay until near the end of the race the sudden change in physiological state in which the energy cost of running and development of fatigue were greatly accelerated. Therefore, the runner should run the first part of his race a little slower than the average speed and make a faster finish in order to utilize the oxygen debt to the maximum. They concluded, if a runner starts out too fast in a race, he acquires most of his oxygen debt at the beginning, before his oxygen intake has

---

[19]F. M. Henry, "Aerobic Oxygen Consumption and Alactic Debt in Muscular Work," Journal of Applied Physiology, Vol. 3 (1951), pp. 427-438.

[20]A. V. Hill, Vol. 16 (1923), p. 148.

[21]R. Margaria et al., Vol. 106 (1933), p. 715.

[22]S. Robinson, D. L. Robinson, D. J. Mountjoy, and R. W. Bullard, "Influence of Fatigue on the Efficiency of Men During Exhaustion Runs," Journal of Applied Physiology, Vol. 12 (1958), pp. 197-201.

reached its maximum, and he was then forced to run the remainder of the race with a high concentration of lactic acid in his muscles.

Matthews and his co-workers[23] conducted an experiment on aerobic and anaerobic work efficiency. Oxygen consumption was determined for seven subjects who rode a bicycle ergometer under three different paces (steady pace, light-heavy pace, and heavy-light pace). The steady pace was found to be significantly better.

The Effects of Exercise on Oxygen Consumption

Wasserman and his associates[24] designed a study to quantify the relationship of metabolism, oxidative sources, and the circulatory and respiratory responses during exercise. The data indicated that the time required for a steady state in oxygen consumption was related to work intensity. A true steady state was reached within four minutes for moderate work, but not, in less than ten minutes, if at all, in the case of very heavy work. Lactate concentration in the blood changed very little at moderate work, increased at heavy work, and increased to a greater degree at the very heavy work intensities. All subjects demonstrated a positive relationship between the oxygen debt and the increase in blood lactate during exercise. The effects of work intensity and duration on metabolic circulatory and ventilatory response to exercise was quantified.

---

[23]D. K. Matthews, R. Bowers, E. Fox, and W. Wilgas, "Aerobic and Anaerobic Work Efficiency," Research Quarterly, Vol. 34 (1963), pp. 356-360.

[24]K. Wasserman, A. Van Kessel, and G. Burton, "Interaction of Physiological Mechanisms During Exercise," Journal of Applied Physiology, Vol. 22 (1967), pp. 71-85.

The purpose of an experiment by Cerretilli and his co-workers[25] was to analyze the energy expenditure as related to the work performance in exercising dogs. Oxygen consumption and lactic acid production were determined at rest and during exercise. With the incline of the treadmill being constant, the oxygen consumption was found to increase linearly with the speed. Also, the lactic acid production increases at higher metabolic levels.

A study to determine relationship in terms of time changes in oxygen consumption and oxygen debt was conducted by Schneider and his associates.[26] Oxygen debt following the exercise periods varied with the intensity and oxygen requirement of the work but did not vary with the duration of work performed at a given rate. The oxygen debt was neither repaid nor increased during work even though the oxygen requirement for the work was far below the man's aerobic capacity. When the oxygen need had developed, the rate of oxygen consumption exactly satisfied this need and no more, thus leaving an oxygen debt to be repaid after exercise.

Welch and his co-researchers[27] observed the ventilatory responses during recovery from muscular work and their relation to oxygen debt.

---

[25]P. Cerretelli, J. Piper, F. Mongili, and B. Ricci, "Aerobic and Anaerobic Metabolism in Exercising Dogs," Journal of Applied Physiology, Vol. 19 (1964), pp. 25-28.

[26]E. G. Schneider, S. Robinson, and J. L. Newton, "Oxygen Debt in Aerobic Work," Journal of Applied Physiology, Vol. 25 (1968), pp. 58-62.

[27]H. G. Welch, J. A. Faulkner, J. K. Barclar, and G. A. Brooks, "Ventilatory Response During Recovery From Muscular Work and Its Relation With O_2 Debt," Medicine and Science in Sports, Vol. 2 (1970), 15-19.

They found that the rate of ventilation was extremely high during severe work and remained elevated during the first few minutes of recovery. The authors concluded that the oxygen cost of breathing during recovery might influence the measurement of oxygen debt.

In discussing the important concepts of the "energy release processes," Knuttgen[28] stated that:

> It was generally accepted that the immediate source of energy for muscle contraction was adenosinetriphosphate (ATP). As ATP served as a linking system in the transfer of energy, the degradation of ATP to adenosine diphosphate and inorganic phosphate must be followed by the resynthesis of ATP in order for energy consuming activity to continue. Creative phosphate (CP) act as a high-energy phosphate reservoir. If ATP and accompanying CP were the sole sources of energy for muscular contraction there would be severe limitations on the length of time that muscular contraction would continue. Therefore, the necessity for the related processes of glycolytic and oxidation phosphocreatine. The breakdown of glycogen to pyruvic acid was referred to as glycolytic phosphorylation. One mole of either glycogen or glucose breaking down to pyruvic acid was responsible for the resynthesis of ATP. It should also be emphasized that in exercise both carbohydrate and free fatty acids served as energy sources.[29]

According to Knuttgen every person has what could be termed an "Anaerobic Capacity." This consists of the energy that could be released without the availability and/or involvement of an appropriate quantity of oxygen. Because of this so-called anaerobic capacity, a person

(a) Can perform physical activity while suspending lung ventilation or,

(b) Can perform a level of activity which demands oxygen

---

[28]H. G. Knuttgen, "Physical Working Capacity and Physical Performance," Medicine and Science in Sports, Vol. 1 (1969), pp. 1-8.

[29]H. G. Knuttgen, (1969), p. 3.

delivery in excess of his aerobic capacity for some minutes.[30]

He further claims that during the recovery from these types of physical efforts, excess oxygen consumptions (oxygen debts) are measured far in excess of the limited oxygen stores the body might have had.

It is Knuttgen's belief that oxygen debt actually constitutes one of the great unsolved problems of exercise physiology. Knuttgen stated that usually when we speak of oxygen debt, people will relate it to lactic acid. He cited some recent findings that disturb the classic concepts of the relationship among hypoxia, lactic acid production, and oxygen debt. They are:

(a) Finding lactic acid production in spite of an apparent abundance of oxygen in the tissues.

(b) Finding the uptake of lactate from the blood by working muscle as well as resting tissue.

(c) Evidence of a possible uncoupling of the reaction in the respiratory chain which could mean a large oxygen consumption, as in recovery, without ATP resynthesis.[31]

Hermansen[32] states in his article on anaerobic energy release that the range of variability of anaerobic work has not been determined, because there has been no accepted test procedure to measure this capacity. According to Hermansen, the use of oxygen debt as a measurement of anaerobic capacity has been considered to be of little

---

[30]H. G. Knuttgen, (1969), p. 4.

[31]Ibid.

[32]L. Hermansen, "Anaerobic Energy Release," Medicine and Science in Sports, Vol. I (1969), pp. 32-38.

importance, due to the fact that several factors are believed to affect the resting oxygen uptake, and consequently the oxygen debt. In spite of this, Hermansen claims, 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 abilities to perform short exhaustive exercise.

Hermansen compared well-trained subjects by looking at their oxygen debt values. These results indicated that the classical concept of oxygen debt may be used to describe a person's ability to perform exhaustive exercise of short duration. His measurements on the swimmers also indicated that the oxygen debt may be increased during a training period.

Cowan and Solandt[33] attempted to solve the problem of the duration of the recovery period following strenuous muscular work. The work they used was performed on a bicycle ergometer. After a preliminary period of 15 minutes pedaling, an eight minute respiratory metabolism was taken. The subject then stepped off the ergometer and ran, in place, as fast as possible for 30 seconds. The subject then resumed his seat on the bicycle and continued pedaling at the former rate. The post-exercise collection was started at the beginning of the mild bicycle exercise and was continued for one and one-half hours after the exercise.

The duration of the recovery period following the running was complete in 20 to 45 minutes using a steady state of mild exercise as

---

[33]C. R. Cowan and O. M. Solandt, "The Duration of the Recovery Period Following Strenuous Muscular Exercise Measured to a Base Line of Steady, Mild Exercise," Journal of Physiology, Vol. 89 (1934), pp. 462-466.

a base line. Recovery to the basal state, after similar exercise, takes at least 90 minutes.

Summary of Related Literature

A. V. Hill, who was an early pioneer in the study of anaerobic work, coined the term "oxygen debt" in 1927. Through the research of Hill and other early leaders[34, 35, 36, 37, 38] the concept of two separate stages of oxygen debt was established. These stages were an alactacid stage and a lactic acid stage.

During the alactacid stage of oxygen debt, light to moderate work loads were performed, and a steady state was maintained during this period. The alactacid debt occurred at the initial phase of work with oxygen debts of up to two and one-half liters per minute, while heart rates were not elevated higher than 160 beats per minute. This stage was accompanied by increases of lactic acid in the muscle tissue, but not in the blood stream, and the debt was quickly repaid generally within three to five minutes.

During the lactic acid stage of oxygen debt there was an accumulation of excessive lactic acid in the blood stream and it was linearly related to the amount of work performed. Heart rates were elevated to above 180 beats per minute and the removal of excessive lactic acid

---

[34] A. U. Hill and H. Lupton, (1923), pp. 135-171.

[35] R. Margaria et al., (1933), pp. 689-715.

[36] R. Margaria et al., Vol. 107 (1934), pp. 681-686.

[37] R. Margaria et al., Vol. 108 (1934), pp. 344-348.

[38] D. B. Dill et al., (1937), pp. 299-307.

during recovery was much slower, taking from 15-90 minutes.

Studies that investigated the effects of training on oxygen debt were also reviewed. The literature established the fact that oxygen debt capacity is trainable.[39, 40, 41, 42]

Gisolfe and his associates[43] conducted a study to look at recovery following exhausting runs. They concluded that it is better for athletes to exercise intermittently at moderate rates following an exhausting competitive event.

In a current article,[44] Knuttgen states that recent findings have challenged the classical concepts of lactic acid production and oxygen debt. It is Knuttgen's belief that oxygen debt actually constitutes one of the great unsolved problems of exercise physiology. The classical concept that oxygen debt may be used to describe a person's ability to perform exhaustive exercise of short duration was confirmed by Hermansen.[45]

[39] S. Robinson, (1951), pp. 428-429.

[40] S. Robinson and P. M. Harmon, (1951), pp. 757-769.

[41] F. M. Henry and W. E. Berg, (1950), pp. 103-111.

[42] L. Hermansen, (1969), pp. 32-38.

[43] C. Gisolfe, S. Robinson, and E. S. Turrell, (1969), pp. 1767-1772.

[44] H. G. Knuttgen, (1962), pp. 629-644.

[45] L. Hermansen, (1969), pp. 32-38.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to propose a method for standardizing the procedures for measuring maximal oxygen debt. A procedure for measuring maximal oxygen debt will be proposed in this chapter.

Selection of Subjects

The subjects were solicited by direct appeal from physical education activity classes which contained only male physical education majors and minors. Forty male subjects between the ages of 17 and 30 years of age volunteered to participate in this study.

Selection of the Procedures for Producing Maximum Oxygen Debt

The initial step was to select a test or exercise that would produce the largest oxygen debt. The various alternatives in the laboratory were to work with the bicycle ergometer or with the treadmill. The treadmill was chosen because previous research[1] has shown that running elicits a greater oxygen debt than any other type of exercise. For this reason the researcher decided to utilize the treadmill. The problem then was narrowed down to what kind of a treadmill test would

[1]Kenneth Cooper, M. D., Aerobics (New York: M. Evans and Co., 1968), p. 29.

be used. Several alternatives were available on the treadmill. These ranged from walking uphill to running at a fast pace on the level to elicit the maximal debt. This part of the study was a pretest to establish a uniform procedure to elicit maximum oxygen debt. Four alternative procedures were chosen and tested using four subjects.

Test one consisted of walking at 3.5 miles per hour (mph) at 8.5 per cent grade for five minutes; then the subject jogged at a speed of seven mph at a grade of three per cent for five minutes. Immediately after the completion of the jog, the subject performed an all-out run at ten mph at seven per cent grade. During the changing of grade and speed, the subject stepped off of the treadmill belt and stood on the mounting platform while the researcher mechanically adjusted the treadmill.

A test developed by Johnson and associates was used as the second test for determining maximum oxygen debt.[2] The subject warmed up by walking at a grade of 8.6 per cent for five minutes at 3.5 mph. After the completion of the warm up, the subject sat on a chair for five minutes. At a signal the subject performed an all-out run at a speed of seven mph and at a grade of 8.6 per cent.

Cureton's All-Out Test for Champion Athletes was chosen for the third test. This test consisted of running to exhaustion at a speed of ten mph and at a grade of 8.6 per cent.[3]

Test four was developed by the author and consisted of two parts.

---

[2] R. E. Johnson, L. Brouha, and R. C. Darling, "A Test of Physical Fitness for Strenuous Exertion," Rev. Canad. Biol., 1 (June, 1942), pp. 491-503.

[3] Thomas K. Cureton, Jr., Physical Fitness of Champion Athletes, The University of Illinois Press, Urbana (1951), p. 314.

The first part was a warm up which involved walking at 3.5 mph at 15 per cent grade for five minutes. The second part required the subject to perform an all-out walk at 3.5 mph at a 30 per cent grade.

The measurement of oxygen debt took place immediately after the all-out performance on each of the four tests, and consisted of measuring the excess oxygen that was consumed during a recovery period of 30 minutes over the subject's resting oxygen consumption. Resting (sitting position) oxygen consumption was taken for three minutes before the exhaustive run. This procedure is described in detail below.

As mentioned above, the author used four subjects to determine which test produced the greatest maximum oxygen debt. A rotation procedure was established to counter-balance training effects.

Test one produced the greatest mean oxygen debt (6.26 liters). Table I lists the debt of each subject on each of the four tests.

TABLE I

MAXIMUM OXYGEN DEBTS
(liters)

Subjects	Test 1	Test 2	Test 3	Test 4
1	8.49 L.	2.00 L.	6.45 L.	6.45 L.
2	6.78 L.	1.80 L.	4.12 L.	6.04 L.
3	5.86 L.	1.48 L.	0.52 L.	5.58 L.
4	3.92 L.	4.07 L.	2.82 L.	3.40 L.
	$\bar{X}$ = 6.26	$\bar{X}$ = 2.34	$\bar{X}$ = 3.48	$\bar{X}$ = 5.37

Test one procedures were then modified to determine if a greater maximum oxygen debt could be obtained. The modification consisted of eliminating the walking stage of the test. This modification produced a greater maximum oxygen debt ($\overline{X}$ = 6.90). Therefore, this test and procedure was selected as the one to be used in this study.

Testing Procedures for the Standardization of Maximum Oxygen Debt

The subjects reported to the Physiology of Exercise Laboratory, located in the Colvin Physical Education Center, during the last week of October, 1970, between 5:00 p.m. and 10:00 p.m. for explanation, demonstration, and practice of testing procedures and orientation to the laboratory equipment.

During the month of November each subject returned to the laboratory to take the maximal oxygen debt test. Most of the subjects reported between 5:00 p.m. and 10:00 p.m. on Monday through Friday. Because of the subjects' schedules, some of the tests were run on the weekends.

The subjects were instructed to report to the laboratory in gym shorts, tennis shoes, and T-shirt. When the subject arrived at the laboratory, he was instructed to rest for five minutes in the sitting position before the test was started. After the rest period, the subjects were asked to remove their shirts and sit down by the Tissot Tank while the electrodes for the E & M Telemetry were attached to their sternum and rib cage. The transmitter was taped on to the side just behind the rib electrode. An ace bandage was then applied to keep electrode movement to a minimum. Following the attachment of the electrodes, the E & M Telemetry Receiver was adjusted for the best possible physiograph reading of the EKG signal. The physiograph was set to have a 0.5 centimeter per second paper speed with the time and event marker recording each second. Resting heart rates were recorded on the physiograph through telemetry with the subject sitting down.

The maximum oxygen debt test was conducted in three steps. The first step was to measure the subject's resting (sitting position) oxygen consumption before the all-out run by having the subject breathe into the Tissot Tank for three minutes. Samples were taken from the Tissot Tank in two liter rubber anasthesia bags, which were analyzed for oxygen and carbon dioxide per cent in the Pulmo-Analyzer. Calculation of resting oxygen consumption was then made by following the procedures outlined in Consolazio's text.[4]

The second phase consisted of the subject jogging at a speed of seven mph at a grade of three per cent for five minutes. At the end of the jog, the subjects' heart rates showed that they were near crest-load.

Immediately after the completion of the jog, the subject performed an all-out run, running as long as possible at ten mph at seven per cent grade. During the changing of the grade and speed, the subject stepped off the treadmill. This change took from ten to 15 seconds of time.

Because motivation of the subjects to produce their maximum effort was very important, the researcher used monetary rewards along with verbal encouragement. The subjects with the longest runs on the treadmill during the all-out run were rewarded monetarily. The best time

---

[4]C. Consolazio et al., (1963), pp. 5-12, 39.

received five dollars and the rewards decreased one dollar for each place down through fifth place.

The third step was the collection of the subjects' expired respiration during recovery in Douglas Bags. At the end of the all-out run the subjects were helped to a stool that was placed nearby, and a large two-way breathing valve (model - "Triple J" Valve: Warren E. Collins, Inc., 220 Wood Road, Baintree, Mass.) was placed in their mouth and a nose clip attached to the nose. This took from three to five seconds. Because of the rapid and heavy breathing from the exhaustive performance, the subject expired his air into a 400 liter Douglas Bag the first 15 minutes. From that point, the respiration was collected in 100 liter bags at five minute intervals. Oxygen consumption was computed after each five minute jog, using Consolazio's[5] method. When the rate of oxygen consumption dropped to within "ten per cent" of the resting consumption, the measurement was stopped.

The respiration collected in the Douglas Bags was transferred into a Collins 100 liter Tissot Tank to obtain an accurate measurement of the volume. Samples were taken from the Tissot Tank in two liter rubber anasthesia bags for analysis.

The first 20 subjects were retested to determine the reliability of the test using the same procedures described above.

Grouping and Analysis of Data

Reliability was determined by test-retest correlation of the first 20 subjects.

---

[5] Ibid.

Product Moment Correlations were computed to determine what relationships existed between maximal oxygen debt and time of work, resting heart rate, heart rate after the jog, maximum heart rate, oxygen consumption at 20 per cent, 15 per cent, and ten per cent above resting oxygen consumption, and oxygen consumption after 30 minutes of recovery, after 45 minutes of recovery, and 60 minutes of recovery. R.Q., oxygen, carbon dioxide, and true oxygen were plotted graphically against time of recovery to check for trends and relationships with oxygen debt repayment.

Summary

The subjects were solicited by direct appeal from physical education activity classes which contained only male physical education majors. Forty male subjects volunteered to participate in this study.

The initial step was to select a test or exercise that would produce the largest oxygen debt. The treadmill apparatus was chosen because previous research had indicated that running would elicit the largest oxygen debt. Four alternative treadmill tests were chosen and tested by using four subjects to find out which would produce the largest debt. These tests ranged from walking uphill to running at a fast pace on the level to elicit the maximal debt. The test that was selected consisted of the subject jogging at a speed of seven mph at a grade of three per cent for five minutes. Immediately after the completion of the jog, the subject performed an all-out run at ten mph at seven per cent grade. During the changing of grade and speed, the subject stepped off of the treadmill. This test was selected because it produced a greater maximum oxygen debt than the other tests.

The subjects were instructed to report to the Physiology of Exercise Laboratory for an explanation, demonstration, and practice of testing procedures and orientation to the equipment. The maximum oxygen debt test was conducted in three steps. The first step was to measure the subject's resting oxygen consumption by having the subject breathe into the Tissot Tank for three minutes. The second phase consisted of the subject jogging for five minutes to warm up and then running until they were exhausted. Immediately after the all-out run the subjects were helped to a stool and their expired respiration was collected in Douglas Bags. Because of rapid and heavy breathing from the exhaustive performance, the subject expired his air into a 400 liter bag for 15 minutes. From that point, the respiration was collected in 100 liter bags at five minute intervals. Oxygen consumption was computed after each five minute jog until it dropped back down to within "ten per cent" of the resting consumption.

Reliability was determined by test-retest correlation of the first 20 subjects. Other correlations were also computed to determine what relationships existed between maximal oxygen debt and the other variables.

CHAPTER IV

RESULTS

The author has attempted to develop and evaluate a laboratory procedure for measuring maximal oxygen debt which could be used by research physiologists.

Reliability

One of the problems that research physiologists have faced in studying maximal oxygen debt has been obtaining reliability for their tests. In a recent article, Welch[1] expressed concern about this problem when he stated that to date researchers have not been able to obtain high reliability coefficients when working with oxygen debt.

The reliability of the proposed procedure was calculated from the retest of the first 20 subjects that took the test. The reliability check produced a correlation of .837, which would indicate that the reliability of this procedure was satisfactory. Matthews[2] noted that reliability coefficients for "physiological variables" could be interpreted as "acceptable" if they were .80 or above. This procedure

---

[1]Hugh G. Welch, John A. Faulkner, Jack K. Barclay, and George Brooks, "Ventilatory Responses During Recovery From Muscular Work and Its Relation With Oxygen Debt," Medicine and Science in Sports, Vol. 2, Spring, 1970, p. 15

[2]Donald K. Matthews, Measurement in Physical Education, W. B. Saunders Co., Philadelphia, 1968, p. 25.

apparently is more reliable than any previous method that has been reported. Matthews also stated that a test could be reliable without being valid, and that validity coefficients may be interpreted as: "fair to good" from .70 to .79, "very good" .80 to .85, "excellent" above .85.[3] Smithells notes that quite a number of "acceptable" validity coefficients may appear in the range of .70 to .79, as their worth is dependent upon the complexity of the variables involved (the administrator, time of day, nearness of last meal, nervousness, and fatigue).

Validity

This study was undertaken with the assumption that logical validity would be used because the test was an oxygen debt test. The fact was accepted that the oxygen debt is that excessive amount of oxygen consumed during recovery over and above what would have been used under normal resting conditions. Any measure that was taken of the excessive oxygen consumption was considered to be a measure of oxygen debt. Karpovich[5] explains oxygen debt by saying that the debt is determined by measuring the total amount of oxygen consumed during the period of recovery. Then the amount of oxygen which would have been normally consumed during the same period if the subject had remained at rest is subtracted to give the amount of oxygen debt.

---

[3]Donald K. Matthews, p. 22.

[4]Phillip A. Smithells and Peter E. Cameron, Principles of Evaluation in Physical Education, Harper and Brothers, New York, 1972, p. 234.

[5]Peter V. Karpovich, Physiology of Muscular Activity, (W. B. Saunders Co., Philadelphia, 1965), p. 57.

Researchers in the past have arbitrarily picked a point to use as a cut-off point for measuring maximal oxygen debt. The cut-off point could either be a time period after the work was completed, or when the oxygen consumption returned to a certain level. Cowan and Solandt[6] used oxygen consumption after a mild exercise on a bicycle ergometer as their baseline. The duration of the recovery period following was completed in from 20 to 45 minutes during a steady state of mild exercise as a baseline. Recovery to the basal state after similar exercise took at least 90 minutes.

This is a good example of why the procedure of arbitrarily picking a cut-off point has been followed. In almost all cases it takes from an hour and a half to two hours for a subject to get back down to his resting oxygen consumption level, which would be the logical way to measure the complete oxygen debt repayment. However, the time involved in following the debt repayment all the way back to resting has made it an impossible situation. Ricci[7] states that post-work oxygen uptake values may not return to pre-work values until 24 to 36 hours later. Because of the problems associated with measuring debt repayment all the way back to resting, the author picked a cut-off point at ten per cent above the resting level.

To illustrate the validity of this test, time of recovery was compared graphically with oxygen intake and percentages above resting

---

[6]C. R. Cowan and O. M. Solandt, "The Duration of the Recovery Period Following Strenuous Muscular Exercise Measured to a Base Line of Steady, Mild Exercise," Journal of Physiology, Vol. 89 (1937), pp. 462-466.

[7]Benjamin Ricci, Physiological Basis of Human Performance, Lea Febiger, Philadelphia (1967), p. 194.

oxygen consumption. Figure 1 shows the relationship between the time of recovery and the amount of oxygen being consumed at different time intervals.

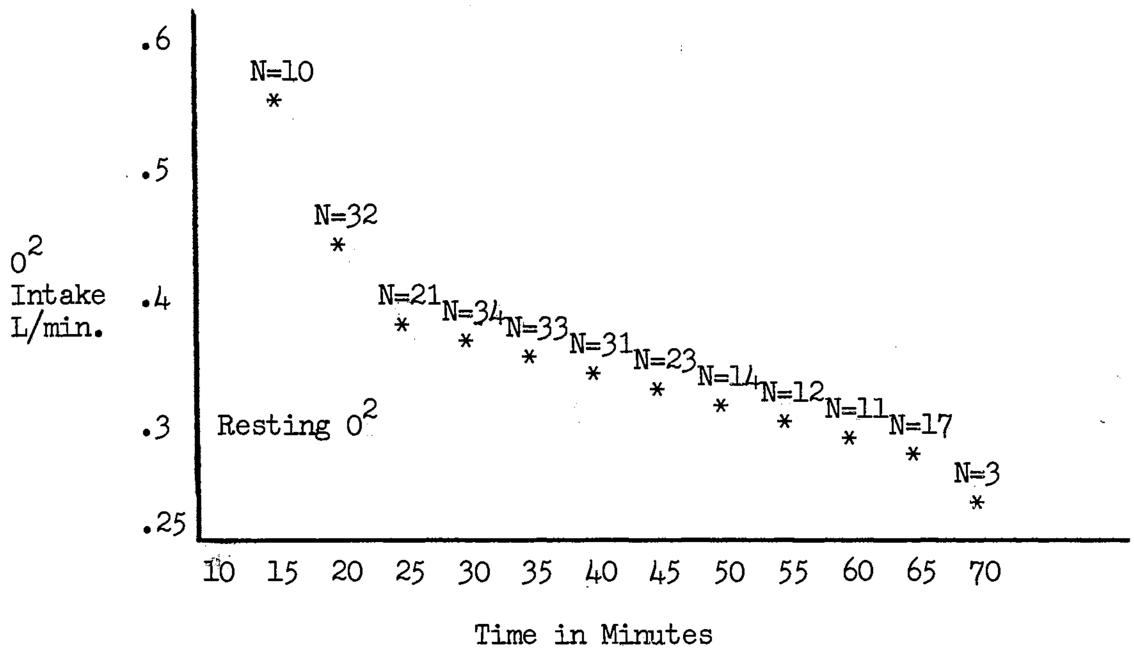

Figure 1. 0^2 Intakes During Recovery

As can be seen by the graph, the oxygen consumption came down steadily from the first measurement to the last. The first samples were taken after 15 minutes of recovery and mean oxygen intake at that point was .53 liters per minute. The largest drop in oxygen consumption occurred during the first 25 minutes as might be expected. The oxygen intake after 20 minutes was .47 liters per minute and after 25 minutes it had dropped to .39 liters per minute. From that point it decreased slowly and uniformly as can be seen by the graph down to .27 liters per minute after 70 minutes of recovery. The .27 is below the mean resting oxygen consumption (.295) for all of the subjects. However, by looking at these three subjects individually it was found that their mean resting oxygen consumption was .265. Even though they were back down below the mean resting level of the population, they had not returned to their individual resting levels.

These data do not add anything to our argument particularly, except that it is typical of the data that other similar studies have found. Henry and DeMoor[8] have shown the same trends on a graph in their study on alactacid and lactacid components of the oxygen debt.

Figure 2 shows the relationship between time of recovery and oxygen consumption rates at 20 per cent, 15 per cent, and ten per cent above resting oxygen consumption. As can be seen from the graph, when the three measurements were plotted, a straight line relationship was found. This would indicate that choosing a percentage above resting oxygen consumption is a valid procedure for measuring debt repayment. Since the relationship is in a straight line, the oxygen consumption rate could be projected all the way back to resting if so desired. The oxygen consumption was back to within 20 per cent of resting after 36 minutes of recovery. It took five more minutes for the oxygen consumption to go on down to 15 per cent above resting (41 minutes). The last calculated reading on the graph shows that oxygen consumption was back to within ten per cent of the resting level after 46 minutes. Assuming that the straight line relationship would continue and the

---

[8] F. M. Henry and J. DeMoor, "Lactic and Alactic Oxygen Consumption in Moderate Exercise of Graded Intensity," Journal of Applied Physiology, Vol. 8 (1956), pp. 608-614.

oxygen consumption would drop at the same rate, two more readings were projected. According to the pattern established, the mean oxygen consumption would have been back down to five per cent above resting after 51 minutes and back down to resting after 56 minutes.

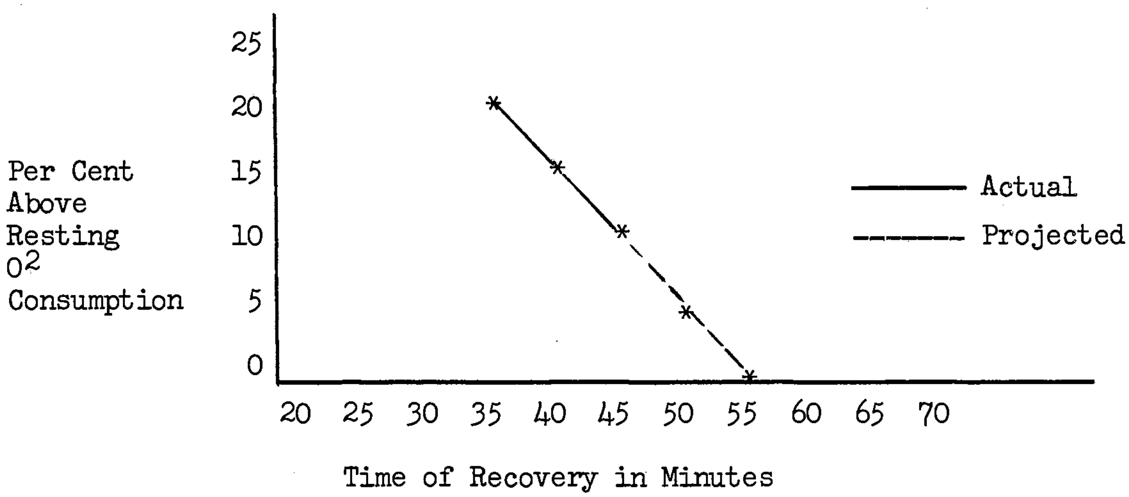

Figure 2. Time Taken for O^2 Consumption to Return to 20 Per Cent, 15 Per Cent and Ten Per Cent Above Resting

Figure 3 shows that rate of oxygen consumption at ten per cent, 15 per cent, and 20 per cent above resting oxygen consumption. A straight line relationship was also noted on this graph. When oxygen consumption had returned to within ten per cent of the resting level the rate of oxygen consumption was .32 liters per minute. The rate of oxygen consumption was .34 liters per minute when it reached 20 per cent above resting. This straight line relationship gives further support to the procedure of choosing the ten per cent above resting oxygen consumption rate as a cut-off point. In fact, in view of the straight line relationship, the cut-off point could arbitrarily be set at 15 per cent or 20 per cent above resting with equal validity.

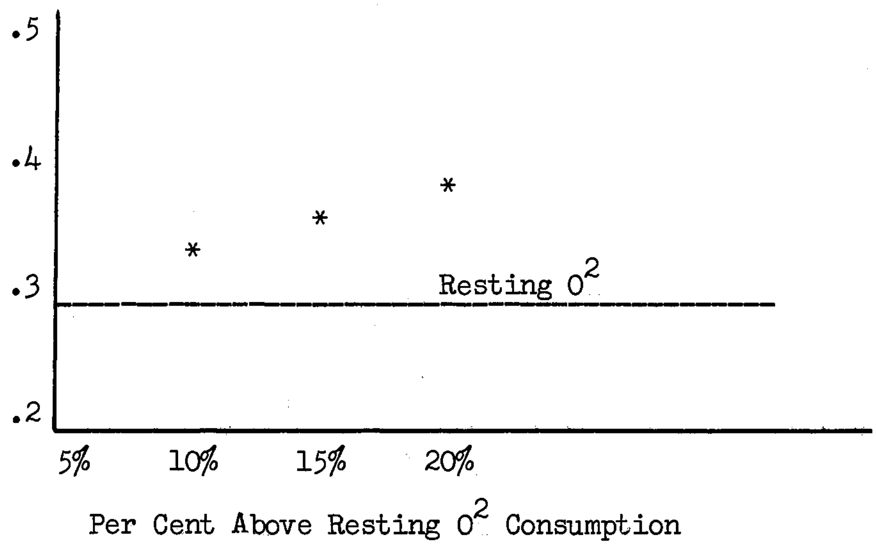

Figure 3. Rate of O^2 Consumption at Ten Per Cent, 15 Per Cent and 20 Per Cent Above Resting O^2 Consumption

Figure 4 further supports the logic of arbitrarily setting a percentage above resting oxygen consumption as the base line when working with maximal oxygen debt. This graph shows the liters of oxygen debt repaid when the oxygen consumption rate had returned to within 20 per cent, 15 per cent, and ten per cent of resting oxygen consumption. A mean debt of 5.7 liters was found after the oxygen consumption had returned to within ten per cent of the resting level. At 15 per cent above resting oxygen consumption 5.0 liters had been repaid. When the oxygen consumption rate reached 20 per cent above resting, 4.2 liters had been repaid. When these figures were plotted on a graph, they also revealed a straight line relationship. The line was extended so that the amount of debt repayment could be projected to resting. The 6.6 liters would have been repaid when the oxygen consumption returned to five per cent above resting. A debt repayment of 7.2 liters was projected when the line was extended back to the level of resting oxygen consumption. This debt repayment (7.20 liters) was very close to the maximal oxygen debt reported by Cureton[9] (7.23 liters) when he tested a group of top athletes. He also reported debt repayments of 7.37 liters for a group of non athletes from the same study, so it would appear that the debts obtained in this study are in line with previous research.

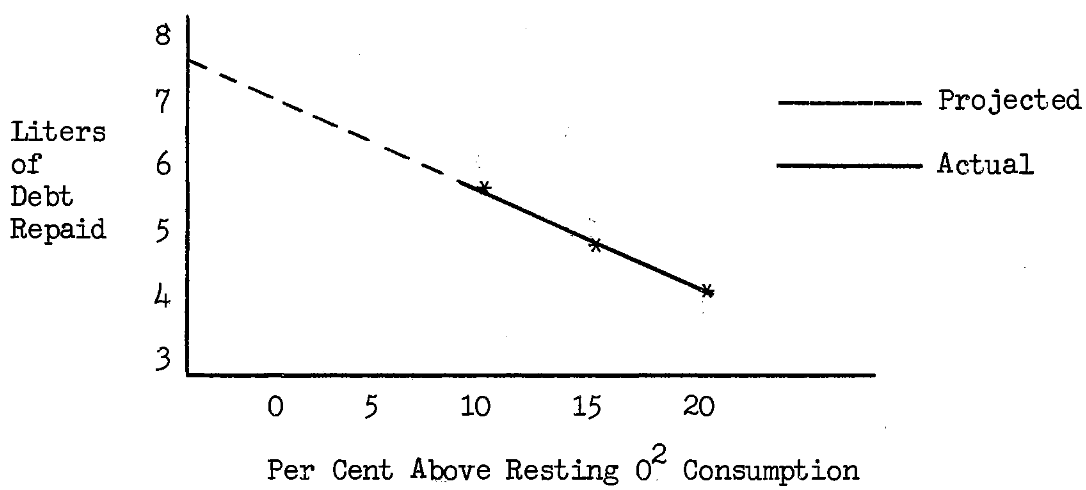

Figure 4. O^2 Debt Repaid at Ten Per Cent, 15 Per Cent, and 20 Per Cent Above Resting O^2 Consumption

[9] Thomas K. Cureton, <u>Physical Fitness of Champion Athletes</u>, The University of Illinois Press, Urbana (1951), pp. 314-350.

Three correlations were calculated between debt repayment after 30 minutes of recovery and debt repayment after the rate of oxygen consumption had returned to 20 per cent, 15 per cent and ten per cent above resting. The 30 minute recovery debt was used because this is an arbitrary time commonly used in many laboratories today. These correlations are mentioned here because they lend more support to the logical validity of the test. All three correlations were high and would fall in the excellent range. Oxygen debt repaid when the rate of oxygen consumption was back to within 20 per cent of resting had a correlation of .875 with debt repaid after 30 minutes of recovery. The correlations went up slightly at the 15 per cent level (.879) and still higher at ten per cent above resting oxygen consumption (.890).

Means and Standard Deviations of Raw Scores

Table II presents the means and standard deviations of the subjects' raw scores on the various measurements taken on the test. The mean maximum oxygen debt produced was 5.7 liters. The range was from 1.29 to 9.37 liters. This debt repayment was somewhat smaller than typical debts reported in other studies.[10] However, when the debts were projected on out to complete recovery, they seemed to be about the same as those reported in other research.

Other interesting and relevant data presented in Table II include the time of the all-out run on the treadmill ($\overline{X}$ = one minute, 52 seconds), resting heart rate ($\overline{X}$ = 75 bpm), heart rate after the treadmill jog ($\overline{X}$ = 182 bpm), and the maximum heart rate after the treadmill

---

[10]Ibid.

TABLE II

MEANS AND STANDARD DEVIATIONS OF VARIABLES MEASURED IN THIS STUDY

Variable	Mean	Standard Deviation
Maximum Oxygen Debt (Liters)	5.714248	2.192345
Time on Treadmill Run (Min. & Sec.)	1 min., 55 sec.	
Resting Heart Rate (bpm)	75.1000	10.6983
H.R. After Treadmill Job for Five Min. (bpm)	182.0000	10.1678
Max. H.R. After Treadmill Run (bpm)	206.9500	9.1596
Time to Reach O_2 Consumption at 20 Per Cent Above Resting Oxygen Consumption (Min.)	36.0000	10.8722
Time to Reach Oxygen Consumption at 15 Per Cent Above Resting Oxygen Consumption (Min.)	41.3750	11.4907
Time to Reach Oxygen Consumption at Ten Per Cent Above Resting Oxygen Consumption (Min.)	46.6250	11.3199
Oxygen Consumption After 30 Minutes Recovery (Liters per Minute)	.38814	.06318
Oxygen Consumption After 45 Minutes Recovery (Liters per Minute)	.292	.1645
Resting Oxygen Consumption (Liters per Minute)	.295	
Oxygen Consumption After 30 Minutes of Recovery (Liters per Minute)	.388	.063

TABLE II (CONTINUED)

Variable	Mean	Standard Deviation
Oxygen Consumption at 20 Per Cent Above Resting (Liters per Minute)	.364	.048
Oxygen Consumption at 15 Per Cent Above Resting (Liters per Minute)	.336	.040
Oxygen Consumption at Ten Per Cent Above Resting (Liters per Minute)	.317	.040
Recovery Time in Minutes	46.62	13.6526

run ($\bar{X}$ = 206 bpm). All of these mean scores tend to lend support to the fact that the testing procedure was a good one for eliciting maximal oxygen debt. Johnson and his associates feel that whatever exercise is used to assess work capacity, the exercise must put the cardiovascular system under considerable stress. The work should be of such intensity that about one-third of all subjects stop from exhaustion within five minutes.[11] The mean time of work on this test was one minute and 52 seconds. The mean heart rate of 182 after the jog was an indication that the subject was near crest load and about to start anaerobic work. The purpose of the jog was to serve as a warm up and bring the subject to near anaerobic stage. We know that anaerobic work starts when the pulse rate is at or near 180 bpm. The mean heart rate of 182 after the jog would indicate that the subjects were sufficiently warmed up and ready to start anaerobic work.

The mean resting heart rate was 75 bpm. The range of the maximal heart rates after the all-out run (192-228) and the mean maximal heart rate (206) indicated that the test required maximal effort from the subjects.

Several means related to the rate of oxygen consumption were also calculated. The oxygen consumption was found to be .364 liters per minute when the consumption rate had returned to within 20 per cent of the resting rate. Oxygen consumption was also compared at 15 per cent and ten per cent above the resting rate and the mean rates were .336 liters and .317 liters per minute respectively. Oxygen consumption was

---

[11] R. E. Johnson, L. Brouha, and R. C. Darling, "A Test of Physical Fitness for Strenuous Exertion," Rev. Canad. Biol., Vol. 1 (June, 1942), p. 8.

checked at intervals after 30 and 45 minutes of recovery. The average rate of oxygen consumption after 30 minutes of recovery was .388 liters per minute and the mean rate of oxygen consumption after 45 minutes of recovery was .332 liters per minute. The resting oxygen consumption was calculated and found to be .295 liters per minute. The time taken to reach levels of oxygen consumption at 20 per cent, 15 per cent, and ten per cent above resting were computed. It took 36 minutes to return to within 20 per cent, 41 minutes to reach 15 per cent, and 46 minutes to get back to ten per cent above resting oxygen consumption.

Correlations at the .01 Level of Confidence

A correlation matrix was constructed to show the relationship between the various measures taken. These intercorrelations are presented in Table III.

The matrix shows 28 correlations that were significant at the .01 level of confidence. One of the first significant correlations on the matrix was between the heart rate after the jog and the heart rate after the all-out run. This correlation was .46, which was significant at the .01 level of confidence. The higher the subject's heart rate, the less fit he is for aerobic work. A subject with a high heart rate on the jog would also have a high heart rate on the all-out run, which is an indication of a lack of fitness for anaerobic work.

There were also significant correlations between maximum oxygen debt and the rate of oxygen consumption after 30 minutes, 45 minutes, and 60 minutes of recovery. These were .71, .68, and .53 respectively. These relationships were expected because as the length of time is extended, the size of the debt increases. Recovery time also produced a

TABLE III

INTERCORRELATION MATRIX OF VARIABLES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Maximum Oxygen Debt (Liters)	1–	1.000														
Resting Heart Rate	2–	.147	1.000													
H.R. After Jog	3–	.004	.141	1.000												
H.R. After Run	4–	.195	.163	.465	1.000											
Oxygen Consumption After 30 Min. Recovery	5–	.711[a]	.116	.034	.129	1.000										
Oxygen Consumption After 45 Min. Recovery	6–	.685[a]	.064	.042	.218	.697[a]	1.000									
Oxygen Consumption After 60 Min. Recovery	7–	.537[a]	–.008	.125	.237	.262	.460[a]	1.000								
Time of Work (in Min. and Sec.)	8–	.256	.050	.669[a]	–.189	.031	.158	.192	1.000							
Oxygen Consumption at 20% Above Resting	9–	–.148	.316[b]	.048	–.022	.285	–.121	–.393[b]	2.286	1.000						
Oxygen Consumption at 15% Above Resting	10–	.114	.465[a]	–.127	.058	.420[a]	.098	–.216	.008	.809[a]	1.000					
Oxygen Consumption at 10% Above Resting	11–	.150	.377[b]	–.098	.100	.499[a]	.070	–.238	–.128	.784[a]	.874[a]	1.000				
Recovery Time in Min.	12–	.709[a]	.084	–.038	.212	.424[a]	.689[a]	.850[a]	.297	–.485[a]	–.175	–.205	1.000			
Carbon Dioxide—When O^2 Consumption was at 10% Above Resting	13–	.323[b]	.193	.081	.200	.126	.209	.430[a]	.083	–.278	–.020	.110	.545[a]	1.000		
R.Q. When O^2 Consumption was at 10% Above Resting	14–	–.080	–.033	.270	–.151	–.382[b]	–.068	.360[b]	–.257	–.342[b]	–.518[a]	.524[a]	.198	.200	1.000	
True Oxygen—When O^2 Consumption was at 10% Above Resting	15–	.272	.121	–.149	.163	.247	.173	.066	.217	–.050	.257	.185	.291	.738[a]	–.373[b]	1.000

a=Significance at the .01 level of confidence, rejection value = .403
b=Significance at the .05 level of confidence, rejection value = .312
N=40
Df=38

significant correlation of .70 with maximal oxygen debt.

Before the performance of the maximum treadmill run, the subject performed a jog on the treadmill for five minutes in order to raise his heart rate variable to near crest load level (heart rate, 180). This jog heart rate variable produced a negative correlation of -.66 with the time on the treadmill run variable. These two measures were inversely related which means that the higher the subject's heart rate during the standardized jog, the shorter the time he would last on the all-out run.

The rate of oxygen consumption after 30 minutes of recovery produced some obvious correlations with time related variables. Other correlations significant at the .01 level between rate of oxygen consumption after 30 minutes recovery were with the rate of oxygen consumption after it had returned to within 15 per cent of resting (.42), oxygen consumption at ten per cent above resting (.49), and time of recovery (.42). Oxygen consumption after 45 minutes of recovery produced a similar correlation of (.69) with the mean time of recovery. The rate of consumption after 60 minutes of recovery produced a high correlation with the time of recovery (.85) and another significant correlation of (.43) with carbon dioxide being produced.

The rate of oxygen consumption at 20 per cent above resting produced a negative correlation of (-.48) with time of recovery. Oxygen consumption at 15 per cent and ten per cent above resting also produced negative correlations. However, they were with RQ's when the oxygen consumption was back to ten per cent of resting. These correlations were (-.51) and (-.57). Recovery time and carbon dioxide had a correlation of .54, and RQ and carbon dioxide a .73. The last correlation at the .01 level of confidence on the matrix was between RQ and oxygen consumption, and it was a negative -.57.

Non-Significant and Special Correlations

Correlations were computed using maximal oxygen debt as the criterion variable with oxygen intake at 15 per cent and 20 per cent above resting, RQ, and true oxygen. These variables showed no significant relationship to maximal oxygen debt. A correlation significant at the .05 level of confidence (.32) was found between maximal oxygen debt and carbon dioxide after oxygen consumption had returned to within ten per cent of the resting level.

The debt repayments at 20 per cent and 15 per cent above resting were correlated with the debt repaid at ten per cent above resting. The correlations were (.80) for 20 per cent above resting and (.83) for 15 per cent above resting, which is significant at the .01 level of confidence.

Summary of Results

The reliability of the test was found to be .837, which would indicate that the procedures were satisfactorily reliable. The reliability check was made by the test-retest method using the first 20 subjects that took the test. This procedure apparently is more reliable than any previous method that has been reported.

This study was undertaken with the assumption that logical validity would be used because the test was any oxygen debt test. The fact was accepted that oxygen debt is that excessive amount of oxygen consumed during recovery. A measure that was taken of the excessive oxygen consumption was considered to be a measure of oxygen debt. Because of the problems associated with measuring debt repayment all the way back down to resting, an arbitrary cut off point of ten per cent above resting was chosen for the baseline in this study. To illustrate the validity of the test, time of recovery was compared graphically with oxygen intake and percentages above resting oxygen consumption. The data in this graph are typical of the data that have been reported in previous research, and therefore, document the fact that the procedures used in this study are valid. Other graphs were presented to show the relationship between time of recovery and oxygen consumption, the rate of oxygen consumption at ten per cent, 15 per cent, and 20 per cent above resting, and oxygen debt repaid when the oxygen consumption rate had returned to within 20 per cent, 15 per cent and ten per cent of resting oxygen consumption. These variables all had a straight line relationship which lends support to the procedure of setting an arbitrary base line at a certain per cent above resting. The straight line trend makes it possible to project what would have happened if the measurement had been continued.

The means from the subjects' raw scores on the various measurements taken pointed out that the test was strenuous enough to elicit maximum oxygen debt. The means of the heart rates after the jog (182) and the all-out run (206) were particularly meaningful. The heart rate of 182 after the jog indicated that the subjects were warmed up and ready to go into anaerobic work. We know that when the heart rate is above 180 bpm the subject is doing anaerobic work. The mean of 206 after the all-out run would indicate that the subjects gave an all-out effort.

A correlation matrix was presented to show the relationship between the various measures taken. There were 28 correlations that were significant at the .01 level of significance. Some of the highest correlations were between maximal oxygen debt and the rate of oxygen consumption after 30 minutes recovery (.71), 45 minutes recovery (.68), and 60 minutes recovery (.53). Recovery time also produced a significant correlation of .70 with maximal oxygen debt. Other relevant correlations included a negative (0.66) with time on the treadmill run and the heart rate after the jog, a (.42) between oxygen consumption after 30 minutes recovery and oxygen consumption after it had returned to within 15 per cent of resting (.42), and at ten per cent above resting (.49). All of these correlations tend to lend support to the assumption that it is logical to arbitrarily set a base line of ten per cent above resting as a cut-off point when working with maximal oxygen debt.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The importance of the oxygen debt capacity of an individual has been recognized by research physiologists for years. There are numerous sports that are performed anaerobically, but there has never been an accepted procedure for eliciting or measuring maximum oxygen debt. Despite attempts to arrive at a uniform method for determining oxygen debt, none has been established which is universally accepted. The research in this area presents a vast number of methods for doing oxygen debt experiments, but the variations in base lines are so great and the period of recovery so variable that they are nearly useless.[1]

The purpose of this study was to develop and evaluate a laboratory procedure for eliciting and measuring maximal oxygen debt, which could be used by research physiologists. To achieve this purpose, four tests that had been previously used to elicit oxygen debt were used in a pre-test experiment to see which one would produce the largest mean oxygen debt. The test that produced the largest debt was modified slightly, and a small increase in oxygen debt was observed. As a result of this pre-testing the following procedures were used to elicit maximal oxygen debt. The subject started with a warm-up jog on the treadmill at a speed of seven miles per hour and at a grade of three per cent for five

---

[1]D. Cunningham, June, 1969.

minutes. Immediately after the completion of the jog, the subject performed an all-out run at ten miles per hour and seven per cent grade. During the changing of the grade and speed the subject stepped off of the treadmill. The subjects' expired air was collected and analyzed during recovery until the oxygen consumption rate returned to within ten per cent of the resting oxygen consumption.

Other problems dealt with specifically were: 1) to determine the reliability of test procedure, 2) to determine if a significant relationship exists between maximal oxygen debt as measured by recovery of oxygen intake to within ten per cent of the resting base line and any one of several recovery variables which might occur before this base line is reached.

Conclusions

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

1. This testing procedure was found to have satisfactory reliability (.837).
2. This testing procedure apparently was a good one for eliciting maximal oxygen debt.
3. The mean debt repaid was 5.7 liters when the oxygen consumption rate was back to within ten per cent of resting. The projected debt with oxygen consumption back to resting was 7.2 liters.
4. The logical validity of the test was supported by straight line relationships between the variables measured.

5. An aribtrary cut-off point could be set at 15 per cent or 20 per cent above resting.
6. Oxygen intake at 15 per cent and 20 per cent above resting did not have a significant relationship with maximal oxygen debt.
7. RQ calculated when oxygen consumption had returned to within ten per cent of resting had no significant relationship with maximal oxygen debt.
8. True oxygen calculated when oxygen consumption had returned to within ten per cent of resting had no significant relationship with maximal oxygen debt.
9. Carbon dioxide calculated when oxygen consumption had returned to within ten per cent of resting had no significant relationship with maximal oxygen debt.

Recommendations

There is no question concerning the importance of understanding more about oxygen debt and its relationship to man's ability to do exhaustive emergency type work.

It appears that a study of maximum oxygen debt using 15 or 20 per cent above resting oxygen consumption as a cut-off point or base line would be a valid approach.

The problem of establishing a base line has been mentioned many times in the literature. The resting base line seems to be the most often used one. However, this tends to create problems because resting oxygen consumptions are often low and the slightest error can cause large discrepancies in the size of oxygen debts. Therefore, it seems logical to conduct further study of oxygen debt using oxygen consumption after a mild exercise as the base line, such as Cowan and Solandt did in 1937.

Reliability has been one of the unsolved mysteries in working with oxygen debt. The procedure proposed in this study had a reliability coefficient of .837, which appears to be higher than any reported to date. It would be helpful if more work using this procedure could be conducted to further check the reliability.

BIBLIOGRAPHY

Block, A. U., D. B. Dill, and H. T. Edwards. "Lactic Acid in the Blood of Resting Man." Journal of Clinical Investigation, Vol. II, 1932.

Cerretelli, P., J. Piper, F. Mongili, and B. Ricci. "Aerobic and Anaerobic Metabolism in Exercising Dogs." Journal of Applied Physiology, Vol. 19, 1964.

Clarke, H. Harrison. Application of Measurement to Health and Physical Education. Prentice-Hall, Inc. (Englewood Cliffs, 1967).

Consolazio, F., R. Johnson, and L. Pecors. Physiological Measurements of Metabolic Functions in Man. (McGraw-Hill Book Company, 1963.)

Cooper, Kenneth, M.D. Aerobics. (New York: M. Evans and Co., 1968.)

Costill, D., W. Hoffman, P. Kehoe, S. J. Miller, and W. C. Myers. "Maximum Anaerobic Power Among College Football Players." The Journal of Sports Medicine, Vol. 8, 1968.

Cowan, C. R. and O. M. Solandt. "The Duration of the Recovery Period Following Strenuous Muscular Exercise Measured to a Base Line of Steady, Mild Exercise." Journal of Physiology, Vol. 89, 1937.

Cunningham, D. A. and J. A. Faulkner. "The Effect of Training on Aerobic and Anaerobic Metabolism During Short Exhaustive Run." Medicine and Science in Sports, Vol. 1, 1969.

Cureton, Thomas K. Physical Fitness of Champion Athletes. (The University of Illinois Press, Urbana, 1951.)

Dill, D. B., H. T. Edwards, E. V. Newman, and R. Margaria. "Analysis of Recovery From Anaerobic Work." Arbeitsphysiologie, Vol. 9, 1937.

Fletcher, W. M., and F. G. Hopkins. "Lactic Acid in Amphibian Muscle." Journal of Physiology, Vol. 35, 1907.

Gisolfi, C., S. Robinson, and E. S. Turrell. "Effect of Aerobic Work Performed During Recovery From Exhausting Work." Journal of Applied Physiology, Vol. 21, 1966.

Harvard, R. E., and G. A. Reaz. "The Influence of Exercise on the Inorganic Phosphates of the Blood and Urine." Journal of Physiology, Vol. 61, 1926.

Henry, F. M. "Aerobic Oxygen Consumption and Alactic Debt in Muscular Work." Journal of Applied Physiology, Vol. 3, 1951.

__________ and W. E. Berg. "Physiological and Performance Changes in Athletic Conditioning." Journal of Applied Physiology, Vol. 3, 1950.

Hermansen, L. "Anaerobic Energy Release." Medicine and Science in Sports, Vol. 1, 1969.

Hill, A. V., C. H. Long, and H. Lupton. "Muscular Exercise, Lactic Acid, and the Supply and Utilization of Oxygen." Medicine and Science in Sports, Vol. 2 (1), 15, 1970.

Hodgson, Pauline. "Studies in the Physiology of Activity: III On Certain Reactions of College Women Following Participation in Three-Court Basketball." Research Quarterly, Vol. 24, 1953.

Johnson, R. E., L. Brouha, and R. C. Darling. "A Test of Physical Fitness for Strenuous Exertion." Revue Canadienne De Biologie, I (June, 1942).

Karpovich, Peter V. Physiology of Muscular Activity. (W. B. Saunders Company, Philadelphia and London, 1965.)

Knuttgen, H. G. "Oxygen Debt, Lactate, Pyruvate, and Excess Lactates After Muscular Work." Journal of Applied Physiology, Vol. 17, 1962.

Knuttgen, H. G. "Physical Working Capacity and Physical Performance." Medicine and Science in Sports, Vol. 1, 1969.

Margaria, R., H. T. Edwards, and D. B. Dill. "The Possible Mechanisms of Contracting and Paying the Oxygen Debt, and the Role of Lactic Acid in Muscular Contraction." American Journal of Physiology, Vol. 106, 1933.

__________ and H. T. Edwards. "The Removal of Lactic Acid From the Body During Recovery From Muscular Exercise." American Journal of Physiology, Vol. 107, 1934.

__________ and H. T. Edwards. "The Sources of Energy in Muscular Work Performed in Anaerobic Conditions." American Journal of Physiology, Vol. 108, 1934.

__________, P. Cerretelli, P. E. DiPrompero, C. Massari, and G. Torelli. "Kinetics and Mechanisms of Oxygen Debt Contraction in Man." Journal of Applied Physiology, Vol. 18, 1963.

__________, P. Aghemo, and E. Rovelli. "Measurement of Muscular Power (Anaerobic) in Man." Journal of Applied Physiology, Vol. 21, 1966.

Matthews, D. K., R. Bowers, E. Fox, and W. Wilgas. "Aerobic and Anaerobic Work Efficiency." Research Quarterly, Vol. 34, 1963.

Matthews, Donald K., and E. L. Fox. The Physiological Basis of Physical Education and Athletics. W. B. Saunders Company (Philadelphia, 1971).

Nagle, F. J., B. Balke, and J. P. Naughton. "Gradational Step Tests for Assessing Work Capacity." Journal of Applied Physiology, July, 1965.

Newman, E. U. "Distribution of Lactic Acid Between Blood Muscle of Rats." American Journal of Physiology, Vol. 122, 1938.

Ricci, Benjamin. Physiological Basis of Human Performance. (Lea and Febiger, Philadelphia, 1967.)

Robinson, S. "Metabolic Adaptations to Exhausting Work as Affected by Training." American Journal of Physiology, Vol. 133, 1941.

__________ and P. M. Harmon. "The Lactic Acid Mechanisms in Relation to Training." American Journal of Physiology, Vol. 132, 1941.

Robinson, S., D. L. Robinson, R. J. Mountjoy, and R. W. Bullard. "Influence of Fatigue on the Efficiency of Men During Exhausting Runs." Journal of Applied Physiology, Vol. 12, 1958.

Schneider, E. G., S. Robinson, and J. L. Newton. "Oxygen Debt in Aerobic Work." Journal of Applied Physiology, Vol. 25, 1968.

Smithells, Philip A., and Peter E. Cameron. Principles of Evaluation in Physical Education. (Harper and Brothers, New York, 1962.)

Wasserman, K., A. Van Kessel, and G. Burton. "Interaction of Physiological Mechanisms During Exercise." Journal of Applied Physiology, Vol. 22, 1967.

Welch, H. G., J. A. Faulkner, J. K. Barclay, and G. A. Brooks. "Ventilatory Response During Recovery From Muscular Work and Its Relation With O_2 Debt." Medicine and Science in Sports, Vol. 2, 1970.

APPENDIX

TABLE IV

RAW DATA

Subject Number	Maximum Oxygen Debt (Liters)	Time on Treadmill Run (Min. & Sec.)	Resting Heart Rate (bpm)	H.R. After Treadmill Jog for 5 Min. (bpm)	Max. H.R. After Treadmill Run (bpm)	Resting Carbon Dioxide (Liters)	Carbon Dioxide With O^2 Consumption at 10% Above Resting (Liters)	Resting Oxygen Consumption (Liters)	True Oxygen at Rest (Liters)	True Oxygen With O^2 Consumption at 10% Above Resting (Liters)	R.Q. Resting	R.Q. With O^2 Consumption at 10% Above Resting
1	8.80	2:11	80	188	200	2.64	2.71	.232	2.45	2.98	1.5	.89
2	8.28	3:33	72	180	204	2.34	2.19	.286	3.41	3.0	.68	.72
3	9.37	1:28	72	192	232	3.02	2.71	.330	2.80	3.97	1.05	.68
4	4.29	1:15	72	184	212	2.11	2.19	.301	3.04	3.05	.70	.74
5	8.73	3:20	76	176	212	2.11	2.19	.292	2.86	3.40	.89	.59
6	4.09	1:15	68	184	196	2.71	2.34	.265	3.15	3.01	.71	.75
7	8.37	1:35	84	180	204	2.26	2.26	.331	2.55	3.42	.60	.64
8	2.53	1:32	60	180	208	2.34	1.73	.278	2.60	2.15	.87	.76
9	8.36	1:31	80	180	212	2.34	1.89	.377	3.25	2.76	.70	.67
10	5.18	0:53	68	196	208	1.58	1.73	.308	2.15	2.13	.73	.78
11	6.22	2:23	72	180	212	2.81	3.09	.236	3.71	4.4	.75	.76
12	4.59	2:02	76	184	204	2.26	1.66	.301	2.35	2.3	.95	.67
13	2.42	1:41	92	184	208	2.19	2.19	.356	1.75	3.17	1.25	.70
14	3.94	1:32	68	168	208	2.11	1.73	.274	1.50	2.17	1.35	.81
15	6.87	1:20	80	188	216	2.56	2.26	.270	2.39	2.95	1.01	.77
16	5.85	1:52	56	176	200	2.79	2.26	.264	3.14	3.1	.87	.72
17	3.95	1:29	72	184	210	2.64	1.96	.317	3.45	2.90	.76	.66
18	5.98	1:12	60	176	196	2.56	2.19	.306	2.82	3.00	.91	.72
19	5.75	0:38	76	192	228	1.96	2.19	.322	2.04	3.5	1.00	.64
20	5.46	3:03	92	160	192	2.79	1.96	.361	2.55	2.9	1.5	.64

TABLE IV (CONTINUED)

Subject Number	Maximum Oxygen Debt (Liters)	Time on Treadmill Run (Min. & Sec.)	Resting Heart Rate (bpm)	H.R. After Treadmill Jog for 5 Min. (bpm)	Max. H.R. After Treadmill Run (bpm)	Resting Carbon Dioxide (Liters)	Carbon Dioxide With O^2 Consumption at 10% Above Resting (Liters)	Resting Oxygen Consumption (Liters)	True Oxygen at Rest (Liters)	True Oxygen With O^2 Consumption at 10% Above Resting (Liters)	R.Q. Resting	R.Q. With O^2 Consumption at 10% Above Resting
21	7.10	1:03	60	192	204	2.49	2.11	.307	2.92	3.2	.85	.66
22	9.23	2:43	84	176	200	2.56	2.19	.285	2.33	3.0	1.1	.74
23	8.33	1:51	80	192	220	2.64	2.71	.248	2.95	3.21	.87	.89
24	4.78	2:17	92	204	224	2.19	1.96	.250	1.95	2.75	1.13	.69
25	1.29	1:26	72	192	200	2.56	2.11	.320	1.72	2.4	1.4	.85
26	2.53	2:08	60	176	208	2.64	1.89	.31	2.84	2.97	.90	.62
27	4.52	1:40	64	180	204	1.96	2.26	.240	2.50	2.89	.80	.79
28	5.48	1:34	72	180	200	2.79	2.49	.313	2.85	3.80	.95	.64
29	5.70	1:35	60	192	204	3.09	1.96	.272	3.5	3.0	.86	.64
30	3.80	1:52	80	176	192	2.19	1.66	.284	2.02	2.33	1.56	.70
31	8.05	1:04	88	192	220	2.64	1.89	.332	2.25	3.04	1.1	.61
32	2.57	1:31	80	188	216	2.79	2.79	.328	4.43	4.27	.64	.64
33	7.09	1:13	100	192	204	2.87	2.56	.347	3.21	3.46	.85	.74
34	3.80	2:15	80	180	204	2.26	1.96	.351	2.62	2.96	.86	.65
35	8.49	5:10	68	148	208	3.02	2.34	.280	2.39	4.87	1.21	.51
36	8.31	1:45	72	188	200	2.26	2.41	.310	2.40	3.05	.90	.79
37	3.70	2:44	64	168	196	2.56	2.04	.262	2.60	2.52	.92	.80
38	5.59	1:30	72	180	200	2.49	2.19	.343	3.0	3.5	.80	.62
39	5.23	2:08	92	172	200	2.26	2.56	.320	2.19	3.3	1.1	.76
40	3.95	1:56	88	180	212	2.41	2.56	.313	2.85	3.61	.81	.69

VITA

Melvin Gene Wright

Candidate for the Degree of

Doctor of Education

Thesis: A SUGGESTED PROCEDURE FOR MEASURING MAXIMAL OXYGEN DEBT

Major Field: Higher Education

Biographical:

Personal Data: Born in Amarillo, Texas, June 4, 1935, the son of Mr. and Mrs. Claude Wright. Married Althea Jacobson, June 23, 1956.

Education: Attended elementary, junior high, and high school in Amarillo, Texas; graduated from Amarillo High School in 1953; received Bachelor of Science degree from Oklahoma State University, May, 1957, with a major in Physical Education; received Master of Science in Physical Education from Baylor University, Waco, Texas, 1959. Completed requirements for Doctor of Education degree in May, 1972.

Professional Experience: Appointed Freshman basketball coach and graduate assistant in the Department of Health, Physical Education, and Recreation, Baylor University, 1957; Professional baseball with the Kansas City Athletics, 1957, 1958, 1959, and 1960 seasons. Appointed physical education teacher and head baseball coach at Amarillo Junior College, Amarillo, Texas, 1965; appointed Head Resident in Oklahoma State University residence hall, 1968; appointed Complex Director of Willham Complex at Oklahoma State University, 1969; appointed Assistant Director of Housing at Oklahoma State University, 1970; appointed Academic Counselor in Oklahoma State University Athletic Department and physical education instructor, 1971; member of the American Association of Health, Physical Education, and Recreation; Oklahoma Association of Health, Physical Education, and Recreation; and American Association of Higher Education.