AN EVALUATION OF THE VALIDITY OF SELECTED TESTS FOR PREDICTING MAXIMAL OXYGEN DEBT

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CHAPTER I

INTRODUCTION

Man has the physiological capacity to perform two types of work: one is labeled aerobic and the other anaerobic, and the capacity for both types of work can be increased by training. Aerobic work is "steady state" work or work during which oxygen intake equals oxygen usage. Under steady state conditions the carbon dioxide production, lactic acid concentration, body temperature, pulse and respiration rates are kept at a fairly constant level, regardless of the time.[1] Each person has a maximum oxygen intake capacity or "crestload." This is usually given as liters per minute (l/min.) or milliliters per kilograms per minute (ml/kg/min.) of oxygen intake capacity and means that a person can take in and use this amount of oxygen each minute for an indefinite time period.

"Aerobics," a physical fitness program developed by an air force physician, Dr. K. H. Cooper, is currently in vogue among civilian and military physical fitness experts. Two books on the topic by this same author have enjoyed

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[1] C. F. Consolazio, R. E. Johnson, and L. J. Pecora. Physiological Measurements of Metabolic Functions in Man. (McGraw-Hill Book Company, 1963, page 12).

wide distribution and attest to the popularity of the program.[2,3]

The term "Aerobics" (with oxygen) was popularized by Dr. Cooper to refer to activity patterns or exercises that result in the creation of accelerated oxygen consumption for extended time periods. These exercises, classified under the category of endurance, serve to tax the individual's capacity to consume oxygen and to deliver it to cells for energy production. The heart rate during aerobic activity usually remains below 180 beats per minute.[4] Dr. Cooper contends that running is the most effective aerobic exercise, and hence, is the most efficient activity in promoting a high level of physical fitness.[5]

The "Aerobics" program appeals to many individuals because it employs a simple test for classification of physical fitness and point system for determining exercise needed. The program is beneficial for most laymen because of its relatively simple nature and yet is based on a large amount of scientific research data. It concentrates heavily on the development of the cardio-respiratory type

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[2] Kenneth H. Cooper, M.D., Aerobics (New York, 1968).

[3] Kenneth H. Cooper, M.D., The New Aerobics (New York, 1970).

[4] Kenneth H. Cooper, 1968, page 104.

[5] Kenneth H. Cooper, 1968, page 25.

of fitness and has as its goal an optimal level of health for the individual.[6]

An empirically tested point system, easy enough for the non-professional to understand, is the core of the "Aerobics" program. The beginner is placed in a suitable program for attaining fitness through a series of exercise-time-elapsed tests. An extremely valuable asset of the program is that no specified activities are required, only that a participant must exercise four days per week and obtain a specified number of exercise points per week. After the participant reaches the "good classification level" of aerobic fitness he is required to obtain 30 aerobic points per week in order to maintain an optimal level of fitness.

The training effect mentioned by Cooper has been empirically demonstrated. Training produces an increase in the maximum level of available oxygen and thus delays the onset of fatigue.[7]

"Anaerobic work" is that which is performed in a short time period and requires a maximum effort from the participant.[8] Man has the physiological capacity to perform this type of work without oxygen for a period of 40-60

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[6] Kenneth H. Cooper, 1968, page x.

[7] Kenneth H. Cooper, 1968, page 13.

[8] Kenneth H. Cooper, 1968, page 21.

seconds. During this work period (40-60 seconds) the muscles are able to contract without oxygen.[9]

The term "oxygen debt" (often used as a synonym for anaerobic activity) is employed to indicate a deficit in oxygen intake during strenuous activity that must be repaid during a recovery period following that activity.[10] Oxygen debt is measured by the excess oxygen beyond the normal resting oxygen intake that is consumed during a recovery period. This type of physical activity has been found to occur at heart rates exceeding 180 beats per minute.[11]

The term, oxygen debt, was introduced by A. V. Hill in 1927.[12] According to Hill's concepts, oxygen debts are constantly being debited and credited. Even slight alterations in body position will result in changes in metabolic activity and hence will involve increased consumption of oxygen. Of course, the oxygen debt initiated by slight changes in body position will be minimal but, nevertheless, oxygen debt will occur.[13]

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[9] Bruno Balke, M.D. "A Simple Field Test for the Assessment of Physical Fitness." Aeromedical Research Division, April 1963, Figure 5, page 7.

[10] Benjamin Ricci. Physiological Basis of Human Performance. Lea and Febiger, Philadelphia, 1967, page 181.

[11] Benjamin Ricci, page 180.

[12] Benjamin Ricci, page 181.

[13] Benjamin Ricci, page 182.

In one of the earliest articles on anaerobic work, Margaria and his associates established the concept of two separate stages of oxygen debt, an "alactacid stage" and a "lactic acid stage."[14] The authors reported that the lactic acid mechanism would not play an important part in muscular contraction except in very strenuous exercise (heart rates exceeding 180 beats per minute). An extensive time period is required for the repayment of oxygen debt from the lactic acid stage of anaerobic work. In the alactacid stage of oxygen debt the heart rate is elevated to about 100-120 beats per minute and the debt is repaid quickly.[15]

In a study by Margaria and Edwards, the authors concluded:

> 1. The increase in lactic acid concentration in the blood following muscular work performed in anaerobic conditions is a linear function of the amount of work.
>
> 2. The fact that this relation is linear suggests that the breakdown of glycogen into lactic acid is really one of the mechanisms for contracting an oxygen debt, and therefore for performing work anaerobically.[16]

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[14] 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: Volume 104, 1933, pages 713-714.

[15] Kenneth H. Cooper, 1968, page 21.

[16] R. Margaria and H. T. Edwards. "The Sources of Energy in Muscular Work Performed in Anaerobic Conditions." American Journal of Physiology: Volume 108, 1934, pages 347-348.

In 1958, William Huckabee of Boston University published a series of papers[17,18] that produced wide discussion. Huckabee concluded that there was no such thing as an alactacid oxygen debt. According to him, virtually the entire debt could be accounted for at all levels of work with lactic acid.

Since Huckabee's work, there have been a number of studies which have investigated the oxygen debt-lactate relationship using Huckabee's innovation, and all have failed to confirm his results. Knuttgen contends that virtually all of the physical activities of everyday living involve the development of an alactacid oxygen debt.[19] The cardiovascular system (heart and blood vessels) is not structured to deliver oxygen immediately when an individual begins an activity. This deficiency of oxygen during the initial stages of activity causes increased oxygen consumption after the termination of exercise. The debt is thus repaid at the termination of exercise and is primarily alactacide in nature.

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[17] W. E. Huckabee. "Relationship of Pyruvate and Lactate During Anaerobic Metabolism. I. Effect of Infusion of Pyruvate or Glucose and of Hyperventilation." Journal of Clinical Investigation 37:244, 1958.

[18] W. E. Huckabee. "Relationship of Pyruvate and Lactate During Anaerobic Metabolism. II. Exercise and Formation of Oxygen Debt." Journal of Clinical Investigation 37:255, 1958.

[19] H. G. Knuttgen. "Symposium on Oxygen Debt." Physiological Aspects of Sports and Physical Fitness. Chicago, 1968, page 9.

Nature of the Problem

There is an emphasis on the development of cardio-respiratory endurance among athletes which is easily understood since an athlete must be able to operate at an optimum pace throughout the duration of an activity. This quality (endurance or aerobic work capacity) is, of course, fundamental to peak performance. A premise developed from a recognition of the role of endurance may be termed "the additive effect;" e.g., if some training is good, more is better. The amount of training necessary to maintain optimal endurance varies from event to event. Coaches in track and swimming employ the stopwatch to determine if an individual is performing at a faster rate. However, the use of the stopwatch is not always possible in sports in which speed and cardio-respiratory endurance are secondary to the skill and strategy of the sport, e.g., the sport of basketball. Therefore, coaches must rely on their past experiences in conditioning their athletic teams.

Training for maximum performance was the main theme of an article by John Faulkner. In it, Faulkner stated:

> ...the improvement in the performance of college runners and swimmers with no change in maximum oxygen uptake is due to increases in the efficiency with which they run or swim at a given speed and in their capacity for anaerobic work.[20]

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[20] John A. Faulkner. "New Perspectives in Training for Maximum Performance." Journal of American Medical Association, Volume 205, September 9, 1968, page 745.

Most distance training programs are essentially designed to develop the oxygen intake capacity of the runner. Since it appears that many runners have attained maximum aerobic capacity by the time they mature, a serious reevaluation of current training practices is needed. A training program to maintain the aerobic capacity and train the anaerobic capacity is very different from the traditional emphasis on distance running (training aerobic capacity).

Aerobic and anaerobic forms of exercise may be found in various degrees in different sports and their applications depend upon the type of sport. Sprinting is a typical example of anaerobic work requiring a maximum effort of the whole body. A large oxygen debt results from this type of activity. Aerobic examples (prolonged efforts) are found in such activities as long-distance running, skiing, cycling, and distance swimming, which essentially call for a steady state of oxygen supply during the larger part of the performance. Only at the start and during the final spurt are anaerobic processes involved.

Many athletic performances are of varied intensity and duration in which bouts of great exertion are alternated with periods of comparatively low activity, such as in the sports of basketball, soccer, hockey, wrestling, football, gymnastics, etc. In these sports, both aerobic and anaerobic processes are involved.

Both aerobic and anaerobic work capacity can be accurately measured in a laboratory environment. Aerobic work capacity can also be validly determined by field tests such as Cooper's 12 minute run for distance[21] and Balke's 15 minute run[22] measured in meters per minute. The procedures for measuring aerobic work have been widely accepted by exercise physiologists and physical educators. Usually, the laboratory procedure consists of measuring the volume of oxygen used during a specified work load by measuring the volume of expired air and determining the per cent of oxygen and carbon dioxide in the expired air.

The laboratory methods for measuring anaerobic work capacity, while generally accepted, have given varying results. Values ranging from 4 - 20 liters have been commonly reported for human subjects.[23,24] The largest oxygen debt (reported by a Russian researcher) was 22.8 liters after a 10,000 meter race.[25] Margaria et al.[26] in

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[21] Kenneth H. Cooper, 1968, page 33.

[22] Bruno Balke, 1963.

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

[24] S. Robinson, 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 Volume 12, 1958, pages 197-201.

[25] Peter V. Karpovich. Physiology of Muscular Activity. In: A. Krestovnikoff. Fiziologia Sporta. Fizkultuva i Sport. Moscow. 1939.

[26] R. Margaria, P. Cerritelli, P. E. diPrampero, C. Massori, and G. Torelli. "Kinetics and Mechanism of Oxygen Debt Contraction in Man." Journal of Applied Physiology, Volume 18, 1963, pages 371-377.

a detailed kinetic analysis, have suggested that the maximum value for the oxygen debt should be only about 4 liters. This value is supported by experiments on dog skeletal muscle.[27,28]

The first stage in the measurement of oxygen debt consists of measuring an individual's basal or resting oxygen consumption. After completion of the initial measurement the subject performs a maximal muscular exercise. Immediately following the exhaustive work the subject's oxygen consumption is taken until it returns to the basal or resting level. Therefore, the laboratory procedure for measuring oxygen debt is time consuming, requiring experimental calculations on an individual basis.

Different size debts have been reported because researchers use different base lines and lengths of time that are allowed for the recovery period in their measurement of oxygen debt. Robinson and his associates[29] used the basal metabolic rate for the baseline in their investigation, whereas Wasserman and his co-workers used resting

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[27] J. Piiper, P. E. diPrampero, and P. Cerritelli. "Oxygen Debt and High Energy Phosphates in Gastrocnemius Muscle of the Dog." American Journal of Physiology, Volume 215, 1918, pages 523-531.

[28] H. G. Welch and W. N. Stainsby. "Oxygen Debt in Contracting Dog Skeletal Muscle in Situ." Respiration Physiology, Volume 3, 1967, pages 229-242.

[29] S. Robinson, 1958.

conditions for the baseline.[30] Cunningham and Faulkner[31] used 12 minutes for the length of the recovery period and Robinson and his associates[32] used over 2 hours for their recovery period. A standardization of procedure for determining the oxygen debt capacity was necessary before research in this important physiological area could be meaningfully interpreted. Wright has attempted to solve this problem with a proposed standardization. In Wright's study the resting oxygen consumption was used as the baseline and the recovery time ceased when the oxygen consumption returned to within ten per cent of the resting oxygen consumption. This measurement of maximum oxygen debt was used as the criterion variable in the present investigation.

To date, the measurement of anaerobic work has been limited to the confines of well equipped laboratories and required time consuming procedures due to the lack of a field test or short laboratory test that would predict oxygen debt capacity. In this investigation, three short laboratory tests and one field test were evaluated in terms of their ability to predict maximum oxygen debt capacity.

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[30] K. Wasserman, G. G. Burton, and A. L. Van Kessel. "Excess Lactate Concept and Oxygen Debt of Exercise." Journal of Applied Physiology, Volume 20, 1965.

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

[32] S. Robinson, 1958.

The four tests were selected on the hypothesis that they relate to anaerobic work capacity based on the criteria that: (1) they require an all-out effort from the participant, and (2) they are performed in a short time period. Following is a brief description of each of the tests (a more detailed description is given in Chapter III).

The "maximal breathing capacity test" consisted of determining how much air a person could move through his lungs in a given time period.[33] This test was selected because maximal breathing is performed in anaerobic work. The apparatus, Tissot Tank, is moderately expensive - $800.00, but the time of performance is only 15 seconds; therefore, mass testing could be conducted if the physical education department could afford the cost of the Tissot Tank.

A short laboratory test consisting of performance on a bicycle ergometer apparatus was developed and designated as "the bicycle ergometer test." The subject pedaled as fast as possible until he achieved a total of 85 revolutions against a resistance of 1200 kilopound meters per minute. This test was usually completed in about 45 seconds. A bicycle ergometer costs approximately $250.00 and is quite portable. If it could be shown to predict maximal oxygen debt it would be feasible for physical educators to use it in testing or training programs.

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[33] C. Consolazio, page 25.

Another short laboratory test was developed and labeled "the treadmill walk test." The speed and work load were established at four miles per hour on a 30 per cent grade. The subject performed as long as possible on the treadmill walk test and the time was used as the recorded measurement. This test was usually completed in two or three minutes. If the treadmill walk test produced a high correlation with the criterion variable (maximum oxygen debt) the necessity of using gas analysis equipment for determining oxygen debt would be eliminated. Treadmills can be purchased in the price range from $500-$5,000.

The field test consisted of timing a subject running up a series of steps, and has been labeled "the step-running test." This test was originally developed by Margaria[34] and then modified by Costill and his associates.[35] Costill et al. concluded that their test was a measurement of anaerobic power. If a significant relationship between the field test and a standardized laboratory test of maximal oxygen debt could be found the field test

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[34] R. Margaria, P. Aghemo, and E. Rovelli. "Measurement of Muscular Power (Anaerobic) in Man." Journal of Applied Physiology: Volume 21, 1966, pages 1662-1664.

[35] D. Costill, W. Hoffman, P. Kehoe, S. J. Miller, and W. C. Myers. "Maximum Anaerobic Power Among College Football Players." The Journal of Sports Medicine: Volume 8, 1968, pages 103-106.

(step running) could be used for mass testing with a minimal amount of equipment, time and expense.

Statement of the Problem

This study was designed to evaluate four practical tests in terms of their ability to predict maximum oxygen debt capacity.

Significance of the Study

As stated previously, numerous sports are performed to some extent anaerobically but only a few techniques have been devised to measure an individual's maximal anaerobic power. Margaria[36] and Costill[37] have established a series of field tests for maximal anaerobic power that were based upon mechanical work output. Unfortunately, these researchers did not correlate their results with any laboratory tests that could accurately measure anaerobic work through the recovery period of oxygen debt. Therefore, what must be developed is a valid, practical test that will be useful to coaches and physical educators with limited time and laboratory equipment.

The development of a practical field test or short laboratory test for predicting maximum oxygen debt capacity would aid physical educators and athletic coaches by

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[36] R. Margaria, 1966, page 1662.

[37] D. Costill, 1968, page 103.

allowing them to determine the anaerobic capacity of their athletes and students. This should be beneficial in the construction of meaningful training programs.

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. Heart Rate - number of times an individual's heart beats per minute.
4. Oxygen Debt - a deficit in oxygen intake during any activity that must be repaid during a recovery period.
5. Maximum Oxygen Debt - the largest amount of oxygen debt an 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 "10 per cent" above his resting oxygen consumption.

Description of Instruments

1. Automatic Performance Analyzer and Contact Pads - an electrical clock instrument used to measure in hundredths of seconds reaction and movement times. Two contact pads were connected to the timing device. When an individual stepped on the first pad, the timing device started. When the second pad was stepped on, the timing device stopped. (Dekan Timing Devices, Glen Ellyn, Illinois; Patent No. 948851; Contact Pads - two, 13 3/4 inches by 22 3/4 inches.)
2. 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.)
3. Monark Bicycle Ergometer - an apparatus for measuring the amount of work performed by a subject. The bicycle ergometer was a stationary bicycle in which the front wheel was replaced by a heavy fly wheel against which the subject performed work. Work was standardized by controlling the pedaling rate (speedometer) and the belt resistance against the wheel. (Resistance Units - Range 0-7 kilopounds; Stockholm, Sweden.)
4. Physiograph - an apparatus that was used to monitor and record heart rate during work and recovery. (Type

PMP-4A-Six Channels; E&M Instrument Co., Inc., Houston, Texas.)

5. 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.)
6. 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.)
7. Tissot Tank - a large stainless steel tank which was used for collecting volumes of expired air during rest and work. (Warren E. Collins Incorporated, 555 Huntington Avenue, Boston 15, Mass.; Capacity-120 liters (0mm-720mm); Serial No. 1440.)
8. Transmitter and Electrodes - equipment that transmitted heart sounds by radio waves into the telemetery apparatus. (Model F.M.-1100-E2, Part No. 98-100-71; E&M Instrument Co., Inc., Houston, Texas.)

Hypotheses

1. A significant and positive relationship at the .05 level of confidence will exist between maximum oxygen debt and the treadmill test time.

2. A significant and negative relationship at the .05 level of confidence will exist between maximum oxygen debt and the bicycle ergometer test results.

3. A significant and positive relationship at the .05 level of confidence will exist between maximum oxygen debt and the maximum breathing capacity test.

4. A significant and negative relationship at the .05 level of confidence will exist between maximum oxygen debt and performance on the step-running test.

Assumptions of the Study

1. The subjects exerted a maximum effort in performing the required tests.

2. The verbal encouragement that was initiated by the researcher had the same motivational effect on all subjects.

3. Verbal encouragement elicited maximum effort from each subject.

4. The orientation of subjects to the equipment and testing procedures relieved testing apprehension.

5. Skill factors would not significantly effect test results because of the nature of the tests which required only the skills of running (leg movement) and breathing.

6. The maximum oxygen debt measurement (criterion variable) used for each subject was a true measure of his anaerobic work capacity.

7. The maximum oxygen debt measurement (criterion variable) resulted from a valid test procedure that produced maximum anaerobic work.

8. All variables being measured are continuous and normally distributed in the whole population, and that any relationship between variables were linear in nature.

Limitation of the Study

Subjects were volunteers and not randomly selected.

CHAPTER II

REVIEW OF RELATED LITERATURE

The purpose of this chapter was to review the important literature associated with the concepts that guided the study.

Studies on Anaerobic Work

A. V. Hill and H. Lupton are two of the first pioneers in the study of lactic acid and oxygen debt. In one of their earliest articles[1] the authors discussed the mechanisms of lactic acid and muscular exercise. The important concepts of their research are given below.

Lactic acid holds a very special position 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 muscular exercise in man is executed at a constant speed the lactic acid content of his active muscles increases gradually from its initial resting minimum. The rise in lactic acid content increases the rate of oxidation so that finally, if the oxygen supply

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

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 as long as exercise at that speed is maintained. If, however, the severity of the exercise is so great that the supply of oxygen cannot cope with the production of lactic acid, no balance is maintained and exhaustion rapidly sets in; therefore, oxygen debt has occurred.

Margaria, Edwards, and Dill[2,3,4] investigated the production and removal of lactic acid and the amount and payment of oxygen debt in man. A summary of their findings 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

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[2] 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: Volume 106, 1933, pages 689-715.

[3] R. Margaria and H. T. Edwards. "The Removal of Lactic Acid from the Body During Recovery from Muscular Exercise." American Journal of Physiology: Volume 107, 1934, pages 681-686.

[4] R. Margaria and H. T. Edwards. "The Sources of Energy in Muscular Work Performed in Anaerobic Conditions." American Journal of Physiology: Volume 108, 1934, pages 344-348.

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 phosphagen split down during muscular contraction.

5. The lactacid oxygen debt starts coming into play only when there may be reason 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.[5]

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

7. The speed of removal of lactic acid during recovery appears to be faster the smaller the amount of lactic acid produced during exercise.[6]

8. 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.

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

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

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[5] R. Margaria et al., 1933, page 715.

[6] R. Margaria et al., 1934, page 686.

> 11. The amount of work performed at the expense of the alactacid mechanism was about half the amount of work attributable to the lactacid mechanism.[7]

Consolazio[8] in his book Physiological Measurement of Metabolic Functions in Man discussed a follow-up study by Dill[9] which confirmed the preceding results.

The mild exercise used as the baseline in an experiment by Cowan and Solandt[10] was performed on a bicycle ergometer. After a preliminary period of fifteen minutes pedaling, one eight minute respiratory metabolism reading was taken. The subject then stepped off the ergometer and ran in place as fast as possible for 30 seconds before resuming his seat on the bicycle and continuing to pedal at the former rate. The first post-exercise collection was begun at the start of the mild bicycle exercise and continued for ten minutes. Successive collections were continued for one and one half hours after the strenuous exercise.

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[7] R. Margaria et al., Volume 108, 1934, page 348.

[8] F. Consolazio, R. Johnson, and L. Pecora. Physiological Measurement of Metabolic Functions in Man. McGraw-Hill Book Company, 1963.

[9] D. B. Dill, H. T. Edwards, E. V. Newman, and R. Margaria. "Analysis of Recovery from Anaerobic Work." Arbeitsphysiologie: Volume 9, 1937, pages 229-307.

[10] 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: Volume 89, 1937, pages 462-466.

The duration of the recovery period following running was completed in from twenty to forty-five minutes using a steady state of mild exercise as a base line instead of the basal state of complete rest. Recovery to the basal state, after similar exercise, took at least ninety minutes.

Nine previously untrained college men were trained for middle distance running during a period of twenty-eight weeks in Robinson's experiment.[11] Timed races on the track were held each week and showed consistent improvement in the running ability of the men. Exhausting runs of three to five minutes duration on a treadmill were repeated at intervals of two to three weeks during the training period. The results indicated that the average maximal oxygen consumption and blood lactic acid increased gradually at the completion of training.

A study by Robinson and Harmon[12] was designed to determine the effects of training upon the lactic acid mechanism in work. The training consisted of a supervised running program with four workouts on the track each week. Observation in the laboratory was made on the subjects before training started and at regular intervals during the training period on the treadmill. During the training

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[11] S. Robinson. "Metabolic Adaptations to Exhausting Work as Affected by Training." American Journal of Physiology: Volume 133, 1941, pages 428-429.

[12] S. Robinson and P. M. Harmon. "The Lactic Acid Mechanism in Relation to Training." American Journal of Physiology: Volume 132, 1941, pages 757-769.

period each time a subject became able to complete five minutes of the exhausting run the grade or speed of both were increased for him in the next test in an attempt to keep the work just severe enough to exhaust him in four to five minutes. The results indicated that the ability of the subjects to accumulate lactic acid during anaerobic work increased with training.

Thomas K. Cureton in 1948[13] studied the physical fitness of champion athletes and developed a treadmill test to measure the oxygen debt capacity of athletes. The maximal physical efficiency test for champion athletes was performed at a speed of 10 miles per hour and a grade of 8.6 per cent on the treadmill apparatus. Subjects performed as long as possible on the test. The average net oxygen debt of the top-athletes was 7.23 liters, while a comparative sample of non-athletes averaged 7.37 liters. The difference was nonsignificant and Cureton concluded that oxygen debt was not a good organic test. There was no way to tell the extent that "will power" influenced the result. Apparently, 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

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

efficiency of "buffering." In this process the lactic acid produced by the working muscles was neutralized in part by the 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 fatigue products (lactic acid) and to facilitate the reconversion, the lactic 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 exercise 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 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 mounted in the trained runner just the same, but the trained runner had by that time run a longer time on the treadmill.

Cureton concluded that oxygen debt was not highly related to all-out running time by itself. He gave the following extraneous factors which interfere with the relationship of performance:

1. skill in running (not tensing up, proper balance, good stride).
2. will power.
3. physical build, especially strength.[14]

In 1958, Willian Huckabee of Boston University published a series of papers[15,16,17,18,19,20] that produced wide discussion. Huckabee concluded that there was no such thing as an alactacid oxygen debt. According to him, virtually the entire debt could be accounted for at all

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[14] Thomas K. Cureton, 1951, page 332.

[15] W. E. Huckabee. "Relationships of Pyruvate and Lactate During Anaerobic Metabolism. I. Effects of Infusion of Pyruvate or Glucose and of Hyperventilation." Journal of Clinical Investigation: Volume 37, 1958, pages 224-235.

[16] W. E. Huckabee. "Relationship of Pyruvate and Lactate During Anaerobic Metabolism. II. Exercise and Formation of O_2 Debt." Journal of Clinical Investigation: Volume 37, 1958, pages 225-263.

[17] W. E. Huckabee. "Relationship of Pyruvate and Lactate During Anaerobic Metabolism. III. Effect of Breathing Low-Oxygen Gases." Journal of Clinical Investigation: Volume 37, 1958, pages 264-271.

[18] W. E. Huckabee. "Relationship of Pyruvate and Lactate During Anaerobic Metabolism: IV. Local Tissue Components of Total Body O_2 Debt." American Journal of Physiology: Volume 196, 1959, pages 253-260.

[19] W. E. Huckabee and W. E. Judson. "The Role of Anaerobic Metabolism in the Performance of Mild Muscular Work. I. Relationship to Oxygen Consumption and Cardiac Output, and the Effect of Congestive Heart Failure." Journal of Clinical Investigation: Volume 37, 1958, pages 1577-1592.

[20] W. E. Huckabee. "The Role of Anaerobic Metabolism in the Performance of Mild Muscular Work. II. The Effect of Asymptomatic Heart Disease." Journal of Clinical Investigation: Volume 37, 1958, pages 1593-1602.

levels of work with lactic acid. Since Huckabee's work there have been a number of studies[21,22,23,24,25] which investigated the oxygen debt-lactate relationship using Huckabee's innovation, and all have failed to confirm his results.

An investigation concerned with evaluating typical performance tests that have been advocated and used was conducted by Henry and Berg.[26] The subjects were freshman basketball players and runners in track. Determination of oxygen debt and carbon dioxide surplus during the recovery period after a moderate standard exercise was made on athletes before and after a regime of physical

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[21] H. G. Knuttgen. "Oxygen Debt, Lactate, Pyruvate, and Excess Lactates After Muscular Work." Journal of Applied Physiology: Volume 17, 1962, pages 639-644.

[22] R. Margaria, P. Cerretelli, P. E. diPrompero, C. Massari, and G. Torelli. "Kinetics and Mechanisms of Oxygen Debt Contraction in Man." Journal of Applied Physiology: Volume 18, 1963, pages 371-377.

[23] R. Margaria, P. Cerretelli, and F. Mangili. "Balance and Kinetics of Anaerobic Energy Release During Strenuous Exercise in Man." Journal of Applied Physiology: Volume 19, 1964, pages 623-628.

[24] K. Wasserman, G. G. Burton, and A. L. Van Kessel. "Excess Lactate Concept and Oxygen Debt of Exercise." Journal of Applied Physiology: Volume 20, 1965, pages 1299-1306.

[25] F. M. Henry and J. DeMoor. "Lactic and Alactic Oxygen Consumption in Moderate Exercise of Graded Intensity." Journal of Applied Physiology: Volume 8, 1956, pages 608-614.

[26] F. M. Henry and W. E. Berg. "Physiological and Performance Changes in Athletic Conditioning." Journal of Applied Physiology: Volume 3, 1950, pages 103-111.

conditioning. Performance scores were also secured on a 300-yard run, short runs, and stool-stepping to exhaustion. Oxygen debt and carbon dioxide production were found to be more effective than performance tests as measures of improvement in physical condition. Conditioning produced a more significant change in amount of debt than in the rate of recovery.

Grollman and Phillips[27] investigated the production of ketone bodies (acetone, acetoacetic, and B-hydroxybutyric acid) in the muscle and blood of untrained and trained rats, both at rest and when completely fatigued. The purpose of their study was to evaluate the possible association of ketone bodies with the alactacid portion of the oxygen debt. The data showed that no ketone bodies were present in the muscle tissue of either the trained or untrained animal at rest. The blood of trained animals at rest had an amount of ketone bodies on the average slightly higher than the untrained. After exhaustive exercise the blood of the trained group contained more ketone bodies than that of the untrained. Results of this experiment with the trained group of animals, made it appear that training made the pathway for fat metabolism more efficient for the acquisition of necessary energy. It was suggested

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[27] S. Grollman and N. E. Phillips. "Possible Relationship of Ketone Bodies to the Alactacid Oxygen Debt." American Journal of Physiology: Volume 177, 1954, pages 73-76.

that accumulated ketone bodies may represent the alactacid portion of the oxygen debt. It was further concluded that training increased the extent to which an animal might derive energy from fat sources, as was evidenced by an increase in ketone body concentration in the blood and muscle of trained animals.

The oxygen intake during exercise and recovery was determined for subjects working on a bicycle ergometer in an experiment by Henry.[28] Experimental results were in accord with Hill's[29] and Margaria's[30] theoretical position that the so-called alactic oxygen is probably not usually 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.

Twenty-two men and twenty women served as subjects for a study by Janice DeMoore.[31] The subjects performed a

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[28] F. M. Henry. "Aerobic Oxygen Consumption and Alactic Debt in Muscular Work." Journal of Applied Physiology: Volume 3, 1951, pages 427-438.

[29] A. V. Hill, Volume 16, 1923, page 148.

[30] R. Margaria et al., Volume 106, 1933, page 715.

[31] Janice DeMoore. "Individual Differences in Oxygen Debt Curves Related to Mechanical Efficiency and Sex." Journal of Applied Physiology: Volume 6, 1954, pages 460-466.

submaximal exercise on an electric bicycle ergometer with the speed held constant. The results indicated that alactic oxygen debts were not related to mechanical efficiency, but less efficient men and women had a large lactate debt component.

Robinson and his associates[32] 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 researchers found that in order to run a given middle distance race in minimum time the runner needed to 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. According to the authors, a 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 started too fast in a race, he acquired most of his oxygen debt at the beginning, before his oxygen intake had 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.

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[32] S. Robinson, D. L. Robinson, D. J. Mountjoy, and R. W. Bullard. "Influence of Fatigue on the Efficiency of Men During Exhausting Runs." Journal of Applied Physiology: Volume 12, 1958, pages 197-201.

Astrand and his associates[33] analyzed blood lactate in cross-country skiers at one to three minutes after the finish in competition. Despite a maximal effort of the skiers, accentuated at the end of the race, there was a successive decrease in the blood lactate concentration with work time. The explanation for the low values after prolonged maximal work, led the researchers to conclude that there was a different kind of fatigue limiting the physical performance depending on the duration of the severe exercise.

The relationship between the respiratory oxygen debt and excess lactate, change in lactate, and change in lactate/pyruvate ratio was examined by Thomas and his associates.[34] The results indicated that the correlation coefficients were poor for all of these variables.

Measurements of oxygen consumption, cardiac output, lactate and pyruvate concentration in arterial blood at rest, during exercise, and during recovery were carried out in twenty patients with heart disease and eight normal volunteers.[35] The level of excess lactate from the

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[33] P. O. Astrand, I. Hallback, R. Hedman, and B. Saltin. "Blood Lactates After Prolonged Severe Exercise." Journal of Applied Physiology: Volume 18, 1963, pages 619-622.

[34] G. D. Thomas, C. Gaos, and C. W. Vaughn. "Respiratory Oxygen Debt and Excess Lactate in Man." Journal of Applied Physiology: Volume 20, 1965, pages 398-402.

[35] H. D. Thomas, B. Boshell, C. Gaos, and T. J. Reeves. "Cardiac Output During Exercise and Anaerobic Metabolism in Man." Journal of Applied Physiology: Volume 19, 1965, pages 839-848.

exercise was found to correlate with the level of oxygen consumption in normal subjects. The patients with subnormal cardiac outputs during exercise had higher excess lactate values and lactate/pyruvate ratios than normal subjects and patients with normal cardiac outputs at similar levels of work.

Gisolfe and associates investigated[36] oxygen debt and the rate of lactate removal in four subjects during recovery following exhausting runs. In one type of experiment the subjects rested throughout recovery, while in another they performed aerobic work for thirty-five or fifty minutes immediately following the exhausting run and then rested. The results showed a reduction of one to two liters in the oxygen debt and a substantial increase in the rate of lactate removal when aerobic work was performed during recovery. Therefore, this study provided a physiological basis for the practice of athletes who have learned from experience that if they exercise intermittently at moderate rates following an exhausting competitive event they will recover more quickly and perform better in later events than if they rest throughout recovery. Such intermittent work might include jogging, walking,

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[36] C. Gisolfe, S. Robinson, and E. S. Turrell. "Effects of Aerobic Work Performed During Recovery from Exhausting Work." Journal of Applied Physiology: Volume 21, 1966, pages 1767-1772.

and resting during the period of recovery between two competitive races.

The purpose of Wasserman and his research associates[37] was to quantify the relationships 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 the metabolic circulatory and ventilatory response to exercise were quantified.

A study to determine relationship in terms of time changes in oxygen consumption and oxygen debt was conducted by Schneider and his associates.[38] Oxygen debt following

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[37] K. Wasserman, A. Van Kessel, and G. Burton. "Interaction of Physiological Mechanisms During Exercise." Journal of Applied Physiology: Volume 22, 1967, pages 71-85.

[38] E. G. Schneider, S. Robinson, and J. L. Newton. "Oxygen Debt in Aerobic Work." Journal of Applied Physiology: Volume 25, 1968, pages 58-62.

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.

Nine experienced middle distance runners completed three experimental runs of equal distance and duration on a motor driven treadmill.[39] Each run varied according to pace (steady, fast-slow-fast, and slow-fast). The researchers found that there were no significant differences among the three pace plans in net oxygen intake during the runs. However, the total oxygen debt value for the steady pace was lower than that for either the fast-slow-fast or the slow-fast paces. It was concluded that a steady pace was most efficient for achieving best time in the mile run.

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[39] W. C. Adams, and E. M. Bernauer. "The Effect of Selected Pace Variations on the Oxygen Requirement of Running a 4:37 Mile." <u>Research Quarterly</u>: Volume 39, 1968, pages 837-846.

Welch and his co-researchers[40] designed a study to observe the ventilatory responses during recovery from muscular work and their relation to oxygen debt. It was 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.

Cunningham and Faulkner[41] studied aerobic and anaerobic metabolism during a short exhaustive run before and after training. The short exhaustive run was performed on a treadmill at a speed of eight miles per hour and a grade of twenty per cent. Pre-training run times ranged from thirty-six to sixty-six seconds. The training program resulted in a twenty-three per cent increase in run time for the short exhaustive run. With training, no change was observed in the oxygen uptake during the first thirty seconds of the short exhaustive run. However, after the initial thirty second period of metabolic adjustment, the oxygen uptake during the remainder of the run

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[40] H. G. Welch, 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: Volume 1, 1969, pages 65-69.

[41] D. A. Cunningham and J. A. Faulkner. "The Effect of Training on Aerobic and Anaerobic Metabolism During Short Exhaustive Runs." Medicine and Science in Sports: Volume 1, 1969, pages 65-69.

was higher after training. Compared to pre-training test results, there was a nine per cent increase in oxygen debt on the post-training test.

Knuttgen[42] discussed the important concepts of the "energy release processes" in his article on the physical working capacity and physical performance of an individual. He 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. Creatine 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 oxidative phosphorylation. 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.[43]

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.

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[42] G. H. Knuttgen. "Physical Working Capacity and Physical Performance." Medicine and Science in Sports: Volume 1, 1969, pages 1-8.

[43] G. H. Knuttgen, 1969, page 3.

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 delivery in excess of his aerobic capacity for some minutes.[44]

He further claims that during the recovery from these types of physical effort, 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. When Knuttgen speaks of oxygen debt, most people will probably relate it to lactic acid. Knuttgen concluded that, some relatively recent findings that disturb the classic concepts of the relationship among hypoxia, lactic acid production, and oxygen debt are that of:

(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 reactions in the respiratory chain which could mean a large oxygen consumption, as in recovery, without ATP resynthesis.[45]

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[44] G. H. Knuttgen, 1969, page 4.

[45] G. H. Knuttgen, 1969, page 4.

In Hermansen's[46] discussion of anaerobic work, it was 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. According to Hermansen, the use of oxygen debt as a measurement of anaerobic capacity has been considered to be of little 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.

Well-trained runners and swimmers were used as the subjects in Hermansen's study. Values for oxygen debt for these athletes were compared with oxygen debts of physical education students and untrained subjects. 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. Measurements on swimmers have also shown that the oxygen debt may be increased during a training period.

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[46] L. Hermansen, "Anaerobic Energy Release." Medicine and Science in Sports: Volume I, 1969, pages 32-38.

Field Tests of Maximum Anaerobic Power

A test for the maximum anaerobic power or the maximal work performance in a short burst of maximal activity in man was developed by Margaria and his associates.[47] The subjects ran at top speed up stairs, two steps at a time. For the measurement of the power the time taken from the fourth to the sixth step was recorded. This time was between .40 to .50 seconds. Thus, the energy release during the first 4 - 5 seconds of maximal exercise is an expression of the maximal anaerobic power.

The theory of maximal work performance was based upon the following statement made by the authors:

> The oxidative reactions in muscle activity, as well as the emergency exergonic process of lactic acid formation from glycogen, are delayed processes and certainly do not contribute to an appreciable extent in the first 4 - 5 seconds of muscular exercise. The power developed in very short exercise of no more than 4 - 5 seconds duration may then be indicative of the phosphagen-splitting mechanisms of work production alone.[48]

Costill and his co-workers[49] compared the anaerobic power among ability grouped college football players and by playing position. The vertical run consisted of

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[47] R. Margaria, P. Aghemo, and E. Rovelli. "Measurement of Muscular Power (Anaerobic) in Man." Journal of Applied Physiology: Volume 21, 1966, pages 1662-1664.

[48] R. Margaria et al., 1966, page 1662.

[49] D. Costill, W. Hoffman, P. Kehoe, S. J. Miller, and W. C. Myers. "Maximum Anaerobic Power Among College Football Players." The Journal of Sports Medicine: Volume 8, 1969, pages 103-106.

running up 10 steps, and the time recorded was between the fourth step and eighth step. The vertical height of each step was 12.6 inches or a combined vertically times distance of 4.2 feet.

When group comparisons were made, vertical velocity was found to be significantly lower in the poor ability group than in either of the superior and average groups. The superior and average players exhibited similar levels of vertical speeds.

Significant differences were observed between all three ability groups as measured by maximum anaerobic power. Such findings were functions of the differences which exist between the mean body weights. Also, anaerobic power was found to be significantly different among various playing positions.

Maximum Breathing Capacity

Baldwin and his associates[50] defined pulmonary insufficiency as a "pathological state producing physical disability, and caused by disordered or inadequate functioning of the lungs." One of the main steps in studying pulmonary function consisted of the measurement of maximum breathing capacity. The maximum breathing

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[50] E. Baldwin, A. Cournand, and D. W. Richards, Jr. "Pulmonary Insufficiency. I. Physiological Classification, Clinical Methods of Analysis, Standard Values in Normal Subjects." <u>Medicine</u>: Volume 27, 1948, pages 243-278.

capacity was the largest volume of air that could be moved in and out of the lungs in a given period of time by voluntary effort. It was measured in liters per minute. The major source of error in the measurement was the author's failure to obtain the full cooperation of the subject. Data was assembled on groups of normal subjects in relationship to physical characteristics. A significant negative correlation with age (-.633, males, -.535, females) was found. No significant correlation with weight or body surface area was demonstrated separately. The best correlation in each sex group was that with both age and body surface area, (-.627, males, -.652, females). From these correlations, the researchers constructed a regression formula, for the prediction of the maximum breathing capacity. Also, it was found that a very high positive correlation (.777, males, .818, females) existed in normal male and female groups between maximum breathing capacity and vital capacity.

The authors concluded that the maximum breathing capacity was the most effective measurement of the bellows action of the chest. A satisfactory performance was dependent upon well coordinated chest movements, a subject's tracheo-bronchial airway movements, and normal elasticity of all parts of the lung. A disturbance in one or in any combination of these factors was reflected in a decreased ability of the individual to move the air in and out of his lungs efficiently and rapidly, and therefore caused a reduction in the predicted normal values.

A standardized procedure for the determination of voluntary ventilation capacity in man was constructed by Gray and his co-workers.[51] The procedure yielded normal values of 167±21 liters per minute for 283 healthy young men and 116±21 liters per minute for 40 healthy young women, with reliability coefficients of .8 to .9. The authors pointed out that voluntary ventilation capacity has had a variety of names, the most common in German being "voluntary maximum ventilation" and in English "maximum breathing capacity." In order to reduce confusion and ambiguity the following self-evident terminology was recommended: voluntary ventilation capacity, exercise ventilation capacity, and CO_2 ventilation capacity.

In their text, Comroe et al.[52] made a distinction between maximal breathing capacity (MBC) and maximal voluntary ventilation (MVV). Maximal breathing capacity was the maximum volume of air that could be breathe per minute. Maximal voluntary ventilation was the maximum volume that was breathed per minute by voluntary effort.

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[51] J. S. Gray, D. R. Barnum, H. W. Matheson, and S. N. Spies. "Ventilatory Function Tests. I. Voluntary Ventilation Capacity." Journal of Clinical Investigation: Volume 29, 1950, pages 677-682.

[52] J. H. Comroe, R. E. Forster, A. B. Dubois, W. A. Briscoe, and E. Carlsen. The Lung: Clinical Physiology and Pulmonary Function Tests. Year Book Medical Publishers Inc., Chicago, 1962, pages 200-203.

The researchers stated that normal figures obtained in different laboratories varied by as much as 30 per cent, according to the type of apparatus used and the resistance it offered to breathing. The authors concluded that until similar apparatus and procedure were employed universally, it seemed inevitable that each laboratory must calibrate its own apparatus and secure its own normal standard values.

Bass, in his text,[53] discussed the significance of the maximum voluntary ventilation test. He believed that the maximum voluntary ventilation test was one of the single most important tests available in respiratory analysis. He felt it represented a final common pathway of ventilation, as it represented the sum total effort of a combination of the will of the patient together with his respiratory muscles and the movement of the lung against its own elastic recoil, and also against the opposing forces of the chest wall. Bass observed that the average healthy man can perform a maximum voluntary ventilation of about 200 liters per minute, and a healthy women can produce up to 150 liters per minute.

Slonim and his co-workers discussed the significance of pulmonary function tests in their book.[54] They stated

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[53] B. H. Bass. Lung Function Tests. London, H. K. Lewis and Co. Ltd., 1966, pages 14-21.

[54] N. B. Slonim, B. P. Bell, S. E. Christensen. Cardio-pulmonary Laboratory Basic Methods and Calculations. Charles C. Thomas, Publishers, 1967, pages 53-58.

that all pulmonary function tests were diagnostic in nature, and were quantitative measures of the various aspects of bronchopulmonary functions, but that, these pulmonary tests could not tell where a lesion was or what it was according to their researchers. Maximal voluntary ventilation differed from other measures of ventilatory capacity in that:

(1) it involves both inspiratory and expiratory phases of ventilation.

(2) it requires voluntary, sustained, maximal effort.

(3) it requires neuromuscular coordination.[55]

Slonim et al. believed that maximal voluntary ventilation was a valuable test when conscientiously performed and properly interpreted, but it was liable to both practice effects and fatigue effects. They felt that usually, maximal ventilation was only achieved by voluntary effort, but the researchers concluded that during exhausting exercise, the ventilation rates of healthy, trained subjects might exceed the maximal voluntary ventilation, probably because of airway dilatation associated with the stress.[56]

The purpose of Stuart and Collings study was to compare the vital capacity and maximum breathing capacity of athletes and nonathletes matched in height, weight, body

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[55] N. B. Slonim, 1967, page 57.

[56] N. B. Slonim, 1967, page 57.

surface area, and age.[57] The mean vital capacity score of the athletes was significantly higher than the mean nonathlete, but nonsignificant differences existed between the two groups in maximal breathing capacity. It was suggested that the difference in vital capacity was due to increased development of respiratory musculature incidental to regular physical training. This increase was not reflected in the maximum breathing capacity since this measurement appeared to be more concerned with the presence or absence of obstructive ventilatory defects that were unaffected by physical training.

Summary of Related Literature

In 1927, the term "oxygen debt" was coined by A. V. Hill who was one of the early pioneers in the study of anaerobic work and its relationship to lactic acid production. Through the research of Hill and other early leaders,[58,59,60,61,62] the concept of two separate stages

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[57] D. G. Stuart and W. D. Collings. "Comparison of Vital Capacity and Maximum Breathing Capacity of Athletes and Nonathletes." Journal of Applied Physiology: Volume 14, 1959, pages 507-509.

[58] A. V. Hill and H. Lupton, 1923, pages 135-171.

[59] R. Margaria et al., 1933, pages 689-715.

[60] R. Margaria et al., Volume 107, 1934, pages 681-686.

[61] R. Margaria et al., Volume 108, 1934, pages 344-348.

[62] D. B. Dill et al., 1937, pages 299-307.

of oxygen debt was established, an alactacid stage and a lactic acid stage.

Light to moderate work loads were performed during the alactacid stage of oxygen debt, and steady state was maintained during this period. The alactacid debt occurred at the initial phase of work with oxygen debts of up to 2 1/2 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 this 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 during recovery was much slower, taking from 15 to 90 minutes.

In 1958, a series of papers[63,64,65,66,67,68] were published by William Huckabee which disputed the early theory of two separate stages of oxygen debt. According

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[63] W. E. Huckabee, Volume 37, 1958, pages 224-235.

[64] W. E. Huckabee, Volume 37, 1958, pages 225-263.

[65] W. E. Huckabee, Volume 37, 1958, pages 264-271.

[66] W. E. Huckabee, 1959, pages 253-260.

[67] W. E. Huckabee, Volume 37, 1958, pages 1577-1592.

[68] W. E. Huckabee, Volume 37, 1958, pages 1593-1602.

to him, the entire debt could be accounted for at all levels of work with lactic acid. Therefore, it was concluded by Huckabee that there was no such thing as an alactacid oxygen debt. Since Huckabee's experiments, there have been a number of follow-up studies[69,70,71,72,73] which have investigated the oxygen debt-lactate relationship using Huckabee's innovation, and all have failed to confirm his results. But Knuttgen, in a current article,[74] states that recent findings have challenged the classical concepts of lactic acid production and oxygen debt. Knuttgen concluded that the lactic acid-oxygen debt concept still constitutes one of the great unsolved problems of exercise physiology.

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[69] H. G. Knuttgen, 1962, pages 629-644.

[70] R. Margaria et al., 1963, pages 371-377.

[71] R. Margaria et al., 1964, pages 623-628.

[72] K. Wasserman et al., 1965, pages 1299-1306.

[73] F. M. Henry and J. DeMoore, 1956, pages 608-614.

[74] G. H. Knuttgen, 1969, page 4.

The literature established the fact that oxygen debt capacity was trainable.[75,76,77,78,79,80] Also, a few researchers[81,82] have constructed field tests to determine the "anaerobic power" of an individual which was based upon mechanical work output. Unfortunately, the researchers did not correlate their results with a true laboratory measurement of oxygen debt capacity.

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[75] S. Robinson, 1941, pages 428-429.

[76] S. Robinson and P. M. Harmon, 1941, pages 757-769.

[77] F. M. Henry and W. E. Berg, 1950, pages 103-111.

[78] S. Grollman and N. E. Phillips, 1954, pages 73-76.

[79] D. A. Cunningham and J. A. Faulkner, 1969, pages 65-69.

[80] L. Hermansen, 1969, pages 32-38.

[81] R. Margaria et al., 1966, pages 1662-1664.

[82] D. Costill et al., 1968, pages 103-106.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to evaluate four tests in terms of their ability to predict maximum oxygen debt capacity, and to determine if the tests were valid, reliable and more efficient in terms of time and expense than the traditional gas analysis measurements of maximum oxygen debt capacity. A possible means of solving the problem is proposed in this chapter.

Subjects

The subjects for the study were forty male physical education majors or minors at Oklahoma State University between seventeen and thirty years of age. The subjects, who were from the physical education activity classes in "Fundamentals of Sports", volunteered to participate in the study.

Testing Procedures and Tests

Three proposed tests of anaerobic capacity, treadmill walk, bicycle ergometer, and maximal breathing capacity, were conducted as "laboratory tests." A fourth test, step-running, was conducted as a "field test," designed to aid physical educators and coaches in predicting anaerobic capacity. It was hypothesized that the four tests selected related to anaerobic work capacity based on the criteria that: (1) each required an all-out effort from the participant, and (2) each was performed in a short time period.

A maximum oxygen debt test which was the criterion variable was administered during the month of November, 1970.

The subjects reported to the Physiology of Exercise Laboratory, located in the Colvin Physical Education Center, during the week of February 1-7, 1971, between 7:00 pm and 10:00 pm, for explanation, demonstration, and practice of testing procedures and orientation to the laboratory equipment. During the second week, February 8-14 between 5:00 pm and 12:00 pm, each subject reported at his assigned time for the treadmill walk test. The following week, February 15-21 between 5:00 pm and 12:00 pm, each subject reported at his assigned time for the bicycle ergometer test. The fourth week, February 22-28 between 5:00 pm and 12:00 pm, each subject reported at his assigned time for the maximal breathing capacity test. During the fifth week, March 1-7 between 4:00 pm and 6:00 pm, each subject reported to the Colvin Physical Education Center at his assigned time for the step-running test.

The subjects were instructed to refrain from participation in any strenuous physical activities for a period of eight hours prior to test administration and from food consumption two hours before testing. Subjects were informed that verbal motivation would be initiated by the researcher during the testing.

Treadmill Walk Test

The first test in the series consisted of the subjects' performance on the treadmill apparatus. Pilot studies had been conducted on graduate students, during the month of January, to determine the best speed and grade to induce maximal oxygen debt in a short time. The physiograph was used to determine the maximal heart rate of the subject. The speed and work load were established at 4 mph (miles per hour) at a 30 per cent grade because it met the criteria as stated. The "excellent" classification on the Balke aerobic treadmill test[1] is performed at a 25 per cent grade (after 25 minutes) and a speed of 3.5 mph. The Balke test is completed when the subject reaches a heart rate of 180 beats per minute. Therefore, it was assumed that by starting at a higher grade and a greater speed the subject should reach anaerobic work (heart rates 180 and above) in a shorter time period. The pilot studies indicated that subjects' were reaching anaerobic work levels in approximately one and one half minutes.

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[1] F. J. Nagle and T. G. Bedecki. "Use of the 180 Heart Rate Response as a Measure of Circulorespiratory Capacity." Research Quarterly, Volume 34, 1963, page 361.

Upon arriving at the laboratory the subject was asked to remove his shirt, sit and rest quietly for five minutes while the electrodes for the Telemetry were attached to his sternum (middle) and rib cage (one inch above and below the nipple). The transmitter was taped to his side just behind the rib electrode and a bandage was applied to keep the transmitter firmly attached during exercise. Following the attachment of the electrodes, the Telemetry receiver was adjusted for the best possible physiograph reading. The physiograph was set to have a .5 centimeter per second paper speed. A time stylus marked each second of elapsed time on the edge of the paper. The resting heart rate of the subject was then recorded on the physiograph through telemetry.

Immediately following the resting pulse rate recording the treadmill walk test was administered. The subject was oriented once again to the treadmill walk test procedure, and was told to assume the starting position by standing on the side of the treadmill platform. On the command "start", the subject placed his right foot lightly on the moving belt of the treadmill to acquaint himself with the speed of the belt. When he had become acquainted with the speed he placed his left foot on the belt and started to walk. At this time a stop watch was started to record the length of performance. The subject walked to exhaustion and upon completion he stepped off the treadmill, sat down immediately, and recovery heart rate was then recorded on the physiograph for five minutes.

Bicycle Ergometer Test

The second test consisted of performance on the Monark bicycle ergometer. Following a series of pre-experiments the work load was established at a resistance of four (four resistance units equals 1200 Kilopound meters/minute) and 85 revolutions were selected because they met the criteria previously stated.

The Astrand submaximal bicycle ergometer test[2] for prediction of aerobic capacity has a standardized resistance ranging from "2 to 3" (600 to 900 Kilopound meters/minute) at a constant speed of 50 pedal revolutions per minute. On this test the subjects performed for five minutes or until the heart rate reached 140 to 150 beats per minute. Since a heart rate above 180 beats per minute was needed, the resistance of 4 (1200 Kilopound meters/minute) was selected. Pilot studies indicated that a resistance of 4 and an all-out effort of a total of 85 revolutions of the pedals would increase the heart rate to above steady state levels.

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[2] P. O. Astrand and I. Ryhming. "A Nomogram for Calculation of Aerobic Capacity (Physical Fitness) from Pulse Rate During Submaximal Work." Journal of Applied Physiology, Volume 7, 1954, pages 218-221.

The pre-exercise procedure for telemetery and heart rate used in the treadmill walk test was also used in the bicycle ergometer test. Following the recording of resting pulse rate the subject was oriented again to the exercise procedure, and was told to assume the starting position on the bicycle. On the command "start," the subject pedaled slowly while the researcher set the resistance at "4"; at this time, the researcher said "go." A stop watch was started at this time to record the length of performance. The subject pedaled as fast as possible and when he had turned the pedals a total of 85 revolutions he was given the command "stop" (stop watch was stopped). During the performance, another researcher counted the number of revolutions out loud to the subject. The count was taken when the right foot was at it highest point. Upon completion of 85 revolutions the subject got off the bicycle, and sat in a chair where recovery heart rate was recorded for five minutes.

Maximal Breathing Capacity Test

Performance on maximal breathing capacity comprised the third test.[3] This test was selected because maximal breathing is performed in anaerobic work. The test

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[3] C. Consolazio, Robert Johnson, and Louis Pecora. Physiological Measurements of Metabolic Functions in Man. McGraw-Hill Book Company, 1963, page 25.

consisted of measuring the amount of air the subject could move through his lungs in a given time period. This was measured by having the subject breathe air into a Tissot Tank for 15 seconds. It was recorded in liters per minute. An example of the maximum breathing capacity calculation procedures are given in Appendix B. During the pre-test period the researcher made sure that the mouthpiece connected to the breathing valve, and a noseclip were securely fitted so that no air could escape. The following specific instructions were given to the subject:

> Breathe forcefully into the mouthpiece at a rate of about two times per second. Do not try to breathe as deeply as you can each breath; do not try to breathe as rapidly as you can. There must be a compromise between rate and depth of breathing to get the best results.

The test was taken in the standing position, and because of light dizziness from the hyperventilation of the test the subjects were given only two trials and the best performance was recorded. A one minute time interval was allowed between trials for recovery. On the command "start", the subject expelled his air into a Tissot Tank for measurement. A stop watch was used to time the procedure for a standardized 15 seconds. At the end of 15 seconds, a valve was turned to direct the exhaled air into the atmosphere and the subject was given the command: "stop." The 15 second results were multiplied by 4 to obtain an estimate of maximal breathing capacity for one minute.

Step-Running Test

Time performance while running up a series of steps completed the series of experiments. A Dekan Automatic Performance Analyzer with contact pads was used to measure the time of the run. The starting line for the subjects was placed 6.5 feet in front of the first step. The first electrical timing pad (start) was placed on the sixth step, while the second pad (stop) was situated on step sixteen. The total vertical rise was 4.5 feet and the horizontal distance was 12.5 feet. Each subject was instructed to run at maximal speed until he was completely past the sixteenth step. The subjects stepped on the second step first and then omitted every other step. Subjects were given three trials and the best performance was recorded as their test score. Figure 1 shows Costill's step-running test and Figure 2 illustrates the step-running test used in this study.

This test was originally developed by Margaria[4] and then modified by Costill and his associates.[5] Costill's steps consisted of a total vertical rise of 4.2 feet.

A pilot study was conducted by this investigator to determine if there was any relationship between various sizes of steps. Three sizes of steps were selected with

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[4] R. Margaria et al., 1966, pages 1662-1664.

[5] D. Costill et al., 1968, pages 103-106.

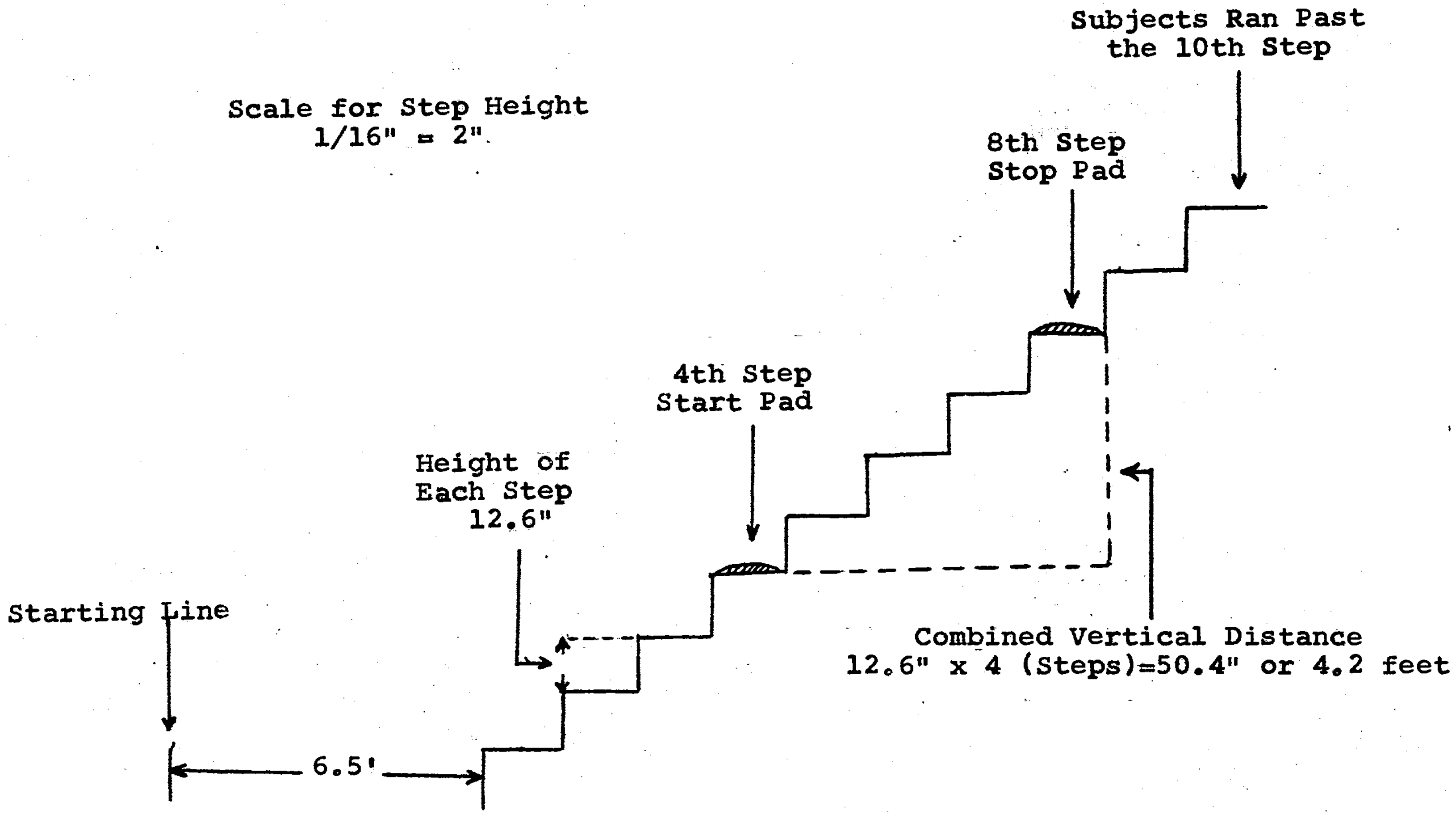

Figure 1. D. Costill et al. Step Running Test (subject stepped on every step)

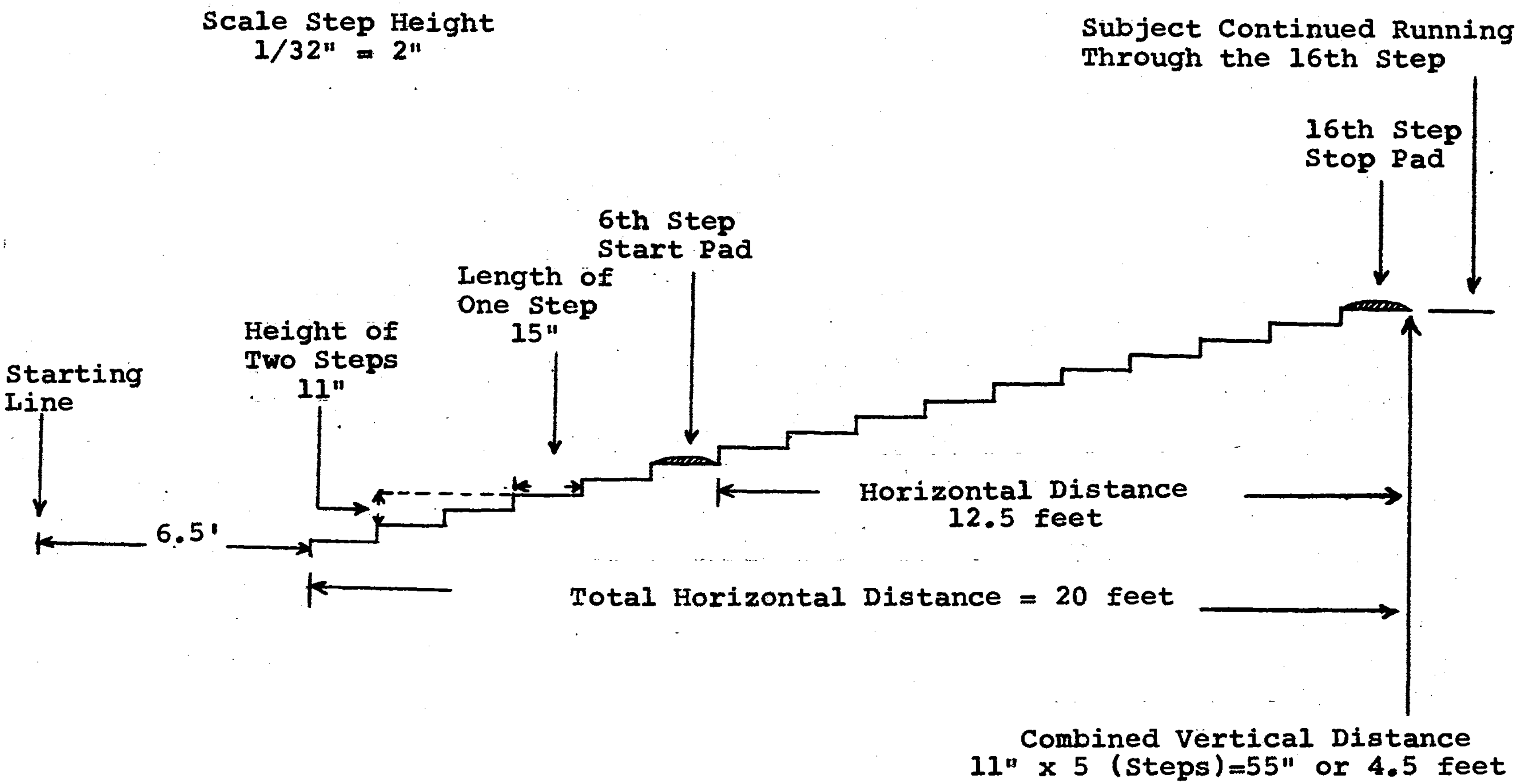

Figure 2. Steps Used in the Present Study (Subjects Stepped on Every Other Step)

the total vertical rise of 4.5 feet, 4.6 feet, and 4.3 feet. Correlations between times in running the three sizes of steps were: r=.851, r=.864, and r=.925. Therefore, it was concluded that with these high correlations, any of the step sizes could be selected as the field test. The one that was selected was 4.5 feet high and was chosen because of its convenient location.

Criterion Variable

The scores on the four tests previously described were correlated with maximum oxygen debt test scores (the criterion variable). The latter test is described below.

The criterion variable consisted of maximum oxygen debt scores obtained on the subjects in a concurrent study conducted by another investigator with the assistance of the writer. Wright[6] developed a test on the treadmill apparatus that measured maximum oxygen debt capacity. It consisted of a subject jogging at a speed of 7 mph at a grade of 3 per cent for five minutes; this caused the heart rate to reach steady state work (mean heart rate was 182 beats per minute). Immediately after the completion of the jog, the subject performed an "all out" run, running as long as possible, at 10 mph at a 7 per cent grade; this produced a mean heart rate of 206 beats per minute. During

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[6] Mel Wright. Dissertation in Process. Oklahoma State University, Stillwater, Oklahoma, May, 1972.

the changing of grade and speed the subject stepped off of the treadmill. This change took from 10 to 15 seconds of time.

Maximum oxygen debt was measured by the amount of excess oxygen consumed by the subject during the recovery period following the completion of the jog and the all-out exhaustive performance. The following procedure was followed with each subject. The first step was a measurement of the subject's resting (sitting position) oxygen consumption for a three minute period before the all-out run. The second step was a performance of the jog and the all-out run. The third step was the collection of the subject's expired respiration in Douglas Bags (100 liters) at timed intervals of 5 minutes, starting after the first fifteen minutes. 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. Samples were taken from the Douglas Bags and per cents of oxygen and carbon dioxide were determined with a Godart pulmo-analyzer. Calculation of oxygen consumption was then made following the procedures outlined in Consolazio's text.[7] When the rate of oxygen consumption dropped to within "ten per cent" of the resting oxygen consumption the measurement was stopped. This procedure produced a

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[7] C. Consolazio et al., 1963, pages 72-78.

reliability coefficient for total oxygen debt repayment of .837.

Grouping and Analysis of Data

The statistical analysis consisted of correlating each of the four experimental test scores with the criterion variable score (maximum oxygen debt.) In addition, multiple correlations between the criterion variable and all possible combinations of four predictor variables were analyzed. Therefore, a total of ten multiple correlations were computed for predictive value. The Pearson-Product Moment correlation and regression equations were used as the statistical tests and all analyses were computed by the Oklahoma State University Computer Center.

The same series of tests was re-administered to ten of the 40 original subjects in order to determine if the four tests were reliable. Pearson-Product Moment correlations were computed on the Wang-Calculator.

While hypotheses were stated in terms of statistical significance (.05 level of confidence) for all tests, r's of .600 and .700 or above would be considered necessary for any one test or combination of tests to be considered a satisfactory predictor of maximum oxygen debt.

CHAPTER IV

RESULTS

This study has attempted to devise tests which could be used by research physiologists, physical educators or coaches to assess maximum oxygen debt capacity with a minimum of equipment and time. Statistical analysis consisted of correlating each of the tests (predictor variables) with a known valid test (criterion variable) of the maximum oxygen debt. Multiple correlations among the five tests were also computed. The Pearson-Product Moment correlation was used as the statistical procedure. Table I presents the means and standard deviations of the subjects' raw scores on the various measurements taken on the five tests.

A correlation matrix was constructed to show the relationships between these various measures. These intercorrelations are presented in Table II. Table III presents the multiple correlations between the maximum oxygen debt and the four predictor variables.

Correlations

The highest coefficient of correlation (.441) was obtained between the maximal breathing capacity test and

TABLE I

MEANS AND STANDARD DEVIATIONS OF VARIABLES MEASURED IN THIS STUDY

Variable		Mean	Standard Deviation
Maximum Oxygen Debt (Liters)	1.	5.714248	2.192345
Time on Treadmill Run (Min. & Sec.)	2.	1.690	.849051
Resting Heart Rate (bpm)	3.	75.1000	10.6983
H.R. After Treadmill Jog for 5 min. (bpm)	4.	182.0000	10.1678
Max. H.R. after Treadmill Run (bpm)	5.	206.9500	9.1596
Time on Treadmill Walk (30% Grade, 4 mph) (Min. & Sec.)	6.	1.950	.839132
Max. H.R. after Treadmill Walk (bpm)	7.	190.6000	7.3205
Bicycle Test (Sec. for 85 Rev./4 Resistance units)	8.	45.85	8.13
Max. H.R. after Bicycle Test (bpm)	9.	183.2000	8.4231
Max. Breathing Test (Liters per min.)	10.	172.0250	38.8904
Step Running Test (Hundreths of Sec.)	11.	1.18	.083
Recovery H.R. for One Min. after Treadmill Walk Test (bpm)	12.	156.8500	13.0317
Recovery H.R. one Min. after Bicycle Test (bpm)	13.	144.3750	10.7266

TABLE II

INTERCORRELATION MATRIX OF VARIABLES

		1*	2*	3*	4*	5*	6	7	8	9	10	11	12	13
Maximum Oxygen Debt (Liters)	*1-	1.000												
Time on Treadmill Run (Min. & Sec.)	*2-	.258	1.000											
Resting Heart Rate	*3-	.147	.064	1.000										
H.R. after Treadmill Jog for 5 min.	*4-	.004	-.664[a]	.141	1.000									
Max. H.R. after Treadmill Run	*5-	.195	-.187	.163	.465[a]	1.000								
Time on Treadmill Walk (30% Grade, 4 mph) (Min. & Sec.)	6-	.161	.851[a]	.012	-.515[a]	-.081	1.000							
Max. H.R. after Treadmill Walk	7-	.173	.0199	.250	.410[a]	.344[b]	.104	1.000						
Bicycle Test (Sec. for 85 Rev./4 resistance units)	8-	-.294	-.329[b]	-.074	.334[b]	-.011	-.386[b]	-.07	1.000					
Max. H.R. after Bicycle Test	9-	.061	.059	.160	.268	.230	.053	.344[b]	-.105	1.000				
Max. Breathing Test (Liters per min.)	10-	.441[a]	.070	.286	.079	.259	.116	.128	-.170	.286	1.000			
Step Running Test (hundreths of Sec.)	11-	-.223	-.394[b]	-.000	.169	.179	-.388[b]	-.100	.466[a]	-.276	-.072	1.000		
Recovery H.R. for One Min. after Treadmill Walk Test	12-	.224	.006	.249	.389[b]	.421[a]	.114	.533[a]	-.287	.236	.155	-.220	1.000	
Recovery H.R. for One Min. after Bicycle Test	13-	.220	-351[b]	.246	.556[a]	.399[b]	-.255	.350[b]	-.252	.376[b]	.208	-.177	.661[a]	1.000

*Wright's Study
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

TABLE III

MULTIPLE CORRELATIONS

Criterion Variable		Predictor Variables	r's
Maximum O_2 Debt	With	Time of Treadmill Run and Time of Treadmill Walk	.282
Maximum O_2 Debt	With	Time of Treadmill Run and Bicycle Ergometer Test	.340[b]
Maximum O_2 Debt	With	Time of Treadmill Run and Max. Breathing Capacity Test	.496[a]
Maximum O_2 Debt	With	Time of Treadmill Run and Step Running Test	.291
Maximum O_2 Debt	With	Time of Treadmill Walk and Bicycle Ergometer Test	.299
Maximum O_2 Debt	With	Time of Treadmill Walk and Max. Breathing Capacity Test	.455[a]
Maximum O_2 Debt	With	Time of Treadmill Walk and Step Running Test	.237
Maximum O_2 Debt	With	Bicycle Ergometer Test and Max. Breathing Capacity Test	.494[a]
Maximum O_2 Debt	With	Bicycle Ergometer Test and Step Running Test	.310
Maximum O_2 Debt	With	Max. Breathing Capacity Test and Step Running Test	.481[a]

a=Significance at the .01 level of confidence, rejection values = .403

b=Significance at the .05 level of confidence, rejection values = .312

N=40

df=38

the maximum oxygen debt measurement. This was significant at the .05 level of confidence. The treadmill walk, bicycle ergometer test, and the step running test revealed nonsignificant relationships with the maximum oxygen debt variable. These coefficients of correlation were all low.

A coefficient of correlation of .851 was found between the time on the maximum treadmill run and the time on the maximum treadmill walk, this was significant at the .05 level of confidence (the rejection level was .312). Since the subjects' time performance on the treadmill run test is highly related to his performance on the treadmill walk test, this is interpreted to mean that these two treadmill tests were measuring the same thing.

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 to near crest-load level (heart rate, 180). This jog heart rate variable produced several significant relationships with some predictor variables. A negative correlation of -.515, significant at .05 level of confidence, was revealed between the jog heart rate variable and time on the treadmill walk for the reason that these two measures were inversely related. This means that the higher the subjects heart rate during the standardized work load, the shorter the time he would last on the all-out walk.

The mean heart rate for the treadmill jog was 182 beats per minute. Other measures that produced a significant relationship with heart rate on the treadmill jog were the maximum heart rate of treadmill walk (.410), bicycle ergometer test (.334), recovery heart rate for one minute on the treadmill walk (.389), and recovery heart rate for one minute on the bicycle ergometer test (.556).

A significant correlation (.344), at the .05 level of confidence, was found between the maximum heart rate of the treadmill run and maximum heart rate of the treadmill walk. Also, significant correlations of .421 and .399 were found between maximum heart rate on the treadmill run and recovery heart rate for one minute after the treadmill walk, and recovery heart rate for one minute after the bicycle ergometer test. Table II presents the above correlations.

Multiple Correlations

Multiple correlation procedures revealed five relationships with maximum oxygen debt which were significant at the .05 level of confidence. The relationship between maximum oxygen debt and the time of the treadmill run and the maximal breathing capacity test revealed an r of .496. The relationship between maximum oxygen debt and time of treadmill walk and maximal breathing capacity test revealed an r of .455. The relationship between maximum oxygen debt and the bicycle ergometer test and maximal breathing capacity test revealed an r of .494. The relationship between maximum oxygen debt and the maximal breathing capacity test and the step-running test revealed an r of .481. A correlation of .340, was found between maximum oxygen debt and the time of treadmill run and the bicycle ergometer test.

Negative, but significant correlations at the .05 level of confidence, were found when correlating the time of the maximum treadmill run with the bicycle ergometer test, step running test, and recovery heart rate for one minute on the bicycle test. These three measures were shown to be inversely related to the time performance on the maximum treadmill run; that is, the longer a subject performed on the maximum treadmill run, the faster he performed on the bicycle and step running test, and the faster his heart rate recovered after the completion of the bicycle test. Refer to Table III for the above information.

Reliability

Table IV contains the reliability of the variables as calculated from the retesting of ten randomly selected subjects. These results show all test procedures to be highly reliable, except for recovery heart rate for one

TABLE IV

RELIABILITY OF VARIABLES

	Variables	r's
1.	Maximum O_2 Debt (N=20)	.837
2.	Time on Treadmill Walk (N=10)	.979
3.	Max. H.R. of Treadmill Walk (N=10)	.850
4.	Bicycle Ergometer Test (N=10)	.863
5.	Max. H.R. of Bicycle Test (N=10)	.937
6.	Max. Breathing Capacity Test (N=10	.986
7.	Step Running Test Time (N=10)	.902
8.	Recovery H.R. for one Min. - Treadmill Walk (N=10)	.710
9.	Recovery H.R. for one Min. - Bicycle Test (N=10)	.942

minute after the treadmill walk. Matthews[1] noted that reliability coefficients for "physiological variables" could be interpreted as "acceptable" if they are .80 or above.

Discussion of Results

Matthews[2] noted that a test could be reliable without being valid, and that validity coefficient may be interpreted as: "fair to good" from .70 to .79, "very good" from .80 to .85, and "excellent" above .85. Smithells[3] notes that quite a number of "acceptable" validity coefficients may appear in the range .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, fatigue).

The highest correlation coefficient (.851) was found between the time on the maximal treadmill run and the time on the maximal treadmill walk. Therefore, this would be in the "excellent" validity classification, according to Matthews. The reliability of the maximal treadmill walk was .979 which is "acceptable" according to Matthews.

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[1] Donald K. Matthews, Measurement in Physical Education, W. B. Saunder Co., Phil. and London, 1968, page 24.

[2] Donald K. Matthews, 1968, page 22.

[3] Phillip A. Smithells and Peter E. Cameron, Principles of Evaluation in Physical Education, Harper and Brothers, New York, 1962, page 234.

The maximal treadmill run test which was used to produce the maximal oxygen debt, had only a .441 correlation coefficient with the maximal breathing capacity test. Although this r of .441 is significant at the .05 level of confidence it is well below the "fair" classification range established by Matthews and Smithells for validity. Therefore, the maximal breathing capacity test should not be used to predict the maximal oxygen debt capacity of an individual.

It was the consensus of the literature that maximum breathing capacity was the most effective measurement of the bellows action of the chest. A satisfactory performance was deemed dependent upon well coordinated neuromuscular chest movements, a subject's tracheo-bronchial airway and normal elasticity of all parts of the lung. A disturbance in any one or a combination of these factors was believed to result in a decreased ability of the individual to move the air in and out of his lungs efficiently and rapidly, thereby causing a reduction in maximum breathing capacity.[4,5,6] A nonsignificant difference in maximum breathing capacity between athletes and non-athletes was found by Stuart and Collings[7] in their

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[4] E. Baldwin et al., 1948, page 265.

[5] B. H. Bass, 1966, page 18.

[6] N. B. Slonim et al., 1967, page 57.

[7] D. G. Stuart, 1969.

investigation. Those authors indicated that maximum breathing capacity appeared to be more concerned with the presence or absence of obstructive ventilatory defects that were "unaffected" by physical training. Therefore, an exercise training program to develop strength and flexibility of the chest movements and lungs probably would not increase the subjects maximal breathing capacity.

Bass[8] concluded that the average healthy man has a maximum breathing capacity of about 200 liters per minute. In Gray's study,[9] 283 healthy young men yielded 167 liters per minute with a standard deviation of 21. In the present investigation the mean maximum breathing capacity was 172 liters per minute with a standard deviation of 38 liters per minute; therefore, this closely coincided with Bass and Gray results. But, as the literature pointed out, until similar apparatus and procedures are employed universally, it seems inevitable that different results will occur. For example, some maximal breathing capacity test measurements are 12 seconds duration while others are 15 seconds.

As previously mentioned, Slonim and his co-researchers[10] concluded that during exhausting exercise, the ventilation

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[8] B. H. Bass, 1966, page 21.

[9] J. S. Gray et al., 1950, page 680.

[10] N. B. Slonim et al., 1967, page 57.

rates of healthy, trained subjects may exceed the maximal voluntary ventilation (maximal breathing capacity), probably because of airway dilatation associated with the stress. Perhaps, some phase of "stress" could be initiated in future experiments to simulate "exhausting exercise."

The treadmill walk test, bicycle ergometer test, and step-running test produced low and nonsignificant relationships and should not be used as predictors for maximal oxygen debt capacity.

The highest multiple correlation (.496) existed between maximal oxygen debt and time of treadmill run and maximal breathing capacity test results. Although this r of .496 is significant at the .05 level of confidence it adds very little to the relationship of maximal breathing capacity alone (.441). Therefore, this combination of the treadmill run and maximal breathing capacity would not be considered sufficiently valid for predicting maximal oxygen debt capacity.

Margaria,[11] Costill and associates[12] concluded that their step-running test was a measurement of anaerobic power. The authors stated that the energy released during the first four to five seconds of maximal exercise was an expression of the maximal anaerobic power of an individual. This was based upon the theory that the power developed

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[11] R. Margaria et al., 1966, page 1664.

[12] D. Costill et al., 1968, page 106.

in very short exercise of no more than four to five seconds duration was an indicator of the phosphagen-splitting mechanism of work production alone.

The step-running test time revealed a negative non-significant relationship of -.223 with the maximal oxygen debt variable. Therefore, the Margaria et al. theory does not appear to be valid when comparing the step-running test with a laboratory measure of maximal oxygen debt.

A mean heart rate of 206 beats per minute revealed that the treadmill run test was a true producer of anaerobic work (heart rates 180 or above). Also, all subjects were tested for oxygen debt by a procedure in which oxygen repayment measurement ceased when a subject reached "ten per cent" above his resting oxygen consumption during the recovery period of debt. This procedure produced a reliability coefficient of .837. There seems to be a difference between the "anaerobic power" advocated by Margaria et al. and "maximal oxygen debt" as measured in a laboratory environment, if one considers the low nonsignificant relationship between these two tests.

Summary of Discussion

It was found that reliabilities of all tests used were high. Treadmill walk test proved highly related to the all-out treadmill run test as evidenced by the r of .851. The mean heart rate after the treadmill walk (193 beats per minute) also indicated that this test was inducing anaerobic work in all subjects.

The maximal breathing capacity test produced a higher relationship with maximal oxygen debt than the treadmill walk test and bicycle test. This was surprising because the bicycle and treadmill test were all-out effort endeavors requiring accelerated oxygen consumption and elevated heart rate. The maximum breathing capacity test only required an individual to move air through his lungs rapidly.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

There are numerous sports that are performed anaerobically but only a few field tests have been constructed to measure an individual's maximal anaerobic power. Time performance while running up a series of steps was originally developed by Margaria[1] and then modified by Costill[2] and his associates to predict the maximal anaerobic power of an individual. These field tests for maximal anaerobic power were based upon mechanical work output. Unfortunately, the authors did not correlate their results with any laboratory test that could accurately measure anaerobic work through the recovery period of oxygen debt. Therefore, there was need for an accurate short laboratory or field test that would correlate as highly as possible with a laboratory test of maximal oxygen debt capacity in order to allow physical educators and coaches to make valid predictions without the use of expensive laboratory equipment and extended time periods.

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[1] R. Margaria, November, 1966.

[2] D. Costill, June, 1968.

The development of a short laboratory or practical field test for predicting maximal oxygen debt would aid physical educators and athletic coaches in the determination of anaerobic capacity. This would be beneficial in the construction of meaningful training programs for athletes and athletic squads.

The purpose of this study was to develop and evaluate four tests in terms of their ability to predict maximal oxygen debt capacity. Statistical analysis consisted of correlating each of the predictor test scores with a criterion variable, which consisted of a maximal oxygen debt test using laboratory gas analysis as developed by Mel Wright.[3] Multiple correlations between maximum oxygen debt and all combinations of the predictor variables were also calculated.

Hypotheses and Findings

Hypotheses were formulated to determine if a significant relationship existed between the maximal oxygen debt variable and the four constructed tests. These hypotheses and the results of testing the hypotheses are presented below along with the other findings.

H.1: A significant and positive relationship will exist between maximal oxygen debt and the treadmill walk

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[3] Mel Wright. Dissertation in Process. Oklahoma State University, Stillwater, Oklahoma.

test time at the .05 level of confidence. Result: A nonsignificant positive relationship (.161) existed between maximal oxygen debt and the treadmill walk test time.

H.2: A significant and negative relationship will exist between maximal oxygen debt and the bicycle ergometer test results at the .05 level of confidence. Result: A nonsignificant negative relationship (-.294) existed between maximal oxygen debt and the bicycle ergometer test results.

H.3: A significant and positive relationship will exist between maximal oxygen debt and the maximal breathing capacity test results at the .05 level of confidence. Result: A significant and positive relationship (.441) existed between maximal oxygen debt and the maximal breathing capacity test results at the .05 level of confidence.

H.4: A significant and negative relationship will exist between maximal oxygen debt and performance on the step running test time at the .05 level of confidence. Result: A nonsignificant negative relationship (-.223) existed between maximal oxygen debt and performance on the step running test time.

5. A significant multiple correlation (.496) existed between maximal oxygen debt and time of treadmill run and maximal breathing capacity test results at the .05 level of confidence.

6. A significant multiple correlation (.455) existed between maximal oxygen debt and time of treadmill walk and

maximal breathing capacity test results at the .05 level of confidence.

7. A significant multiple correlation (.494) existed between maximal oxygen debt and bicycle ergometer test results and maximal breathing capacity test results at the .05 level of confidence.

8. A significant multiple correlation (.481) existed between maximal oxygen debt and maximal breathing test results and performance on the step running test time at the .05 level of confidence.

9. A significant multiple correlation (.340) existed between maximal oxygen debt and time on treadmill run and bicycle ergometer test results at the .05 level of confidence.

10. None of these tests had a high enough correlation coefficient with maximum oxygen debt to be considered valid predictors.

Recommendations

There is still a need to develop a practical test that will predict maximal oxygen debt capacity without the use of expensive laboratory equipment and extended time periods.

Track events that are under a mile run (50 yard dash, 100 yard dash, 220 yard dash, 440 yard dash, 880 yard dash) have been found to be primarily anaerobic work; therefore, these distances could be analyzed in future studies to determine if a relationship between these events and maximum oxygen debt exist. Also, the use of other tests such as the vertical jump in combination with the maximum breathing capacity test could be tried to predict maximum oxygen debt.

A future experiment could employ a factorial analysis design to determine what variables are related to "anaerobic power." The following variables might be investigated: leg strength, leg size, body weight, height, and body surface area.

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APPENDIX A

RAW DATA FROM WRIGHT'S STUDY

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)
1	8.80	2:11	80	188	200
2	8.28	3:33	72	180	204
3	9.37	1:28	72	192	232
4	4.29	1:15	72	184	212
5	8.73	3:20	76	176	212
6	4.09	1:15	68	184	196
7	8.37	1:35	84	180	204
8	2.53	1:32	60	180	208
9	8.36	1:31	80	180	212
10	5.18	0:53	68	196	208
11	6.22	2:23	72	180	212
12	4.59	2:02	76	184	204
13	2.42	1:41	92	184	208
14	3.94	1:32	68	168	208
15	6.87	1:20	80	188	216
16	5.85	1:52	56	176	200
17	3.95	1:29	72	184	210
18	5.98	1:12	60	176	196
19	5.75	0:38	76	192	228
20	5.46	3:03	92	160	192

RAW DATA FROM WRIGHT'S STUDY (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)
21	7.10	1:03	60	192	204
22	9.23	2:43	84	176	200
23	8.33	1:51	80	192	220
24	4.78	2:17	92	204	224
25	1.29	1:26	72	192	200
26	2.53	2:08	60	176	208
27	4.52	1:40	64	180	204
28	5.48	1:34	72	180	200
29	5.70	1:35	60	192	204
30	3.80	1:52	80	176	192
31	8.05	1:04	88	192	220
32	2.57	1:31	80	188	216
33	7.09	1:13	100	192	204
34	3.80	2:15	80	180	204
35	8.49	5:10	68	148	208
36	8.31	1:45	72	188	200
37	3.70	2:44	64	168	196
38	5.59	1:30	72	180	200
39	5.23	2:08	92	172	200
40	3.95	1:56	88	180	212

RAW DATA

Subject Number	Time on Treadmill Walk (30% Grade, 4 mph) (Min.& Sec.)	Max. H.R. after Treadmill Walk (bpm)	Bicycle Test (Sec. for 85 Rev/4 Resistance units)	Max. H.R. after Bicycle Test (bpm)	Max. Breathing Test (Liters per min.)	Step Running Test (Hundreths of Sec.)	Recovery H.R. for one min. after Treadmill Walk Test (bpm)	Recovery H.R. for one min. after Bicycle Test (bpm)
1	2:15	196	39	188	183	1.10	148	148
2	3:05	200	46	188	147	1.05	168	148
3	1:36	200	37	190	273	1.18	184	164
4	1:25	184	50	188	187	1.18	152	140
5	3:01	188	49	180	168	1.22	168	140
6	1:15	180	80	176	208	1.23	120	121
7	1:36	192	44	196	187	1.12	152	148
8	1:40	184	46	176	112	1.19	152	136
9	1:50	192	33	176	230	1.12	156	144
10	1:39	192	49	180	178	1.18	168	152
11	1:50	192	52	196	197	1.15	140	132
12	2:08	188	45	196	226	1.19	156	152
13	2:23	192	42	188	235	1.20	156	154
14	1:55	184	40	188	144	1.13	140	148
15	2:27	196	42	168	173	1.08	176	156
16	1:35	186	40	188	139	1.14	168	156
17	2:03	204	49	184	155	1.37	160	140
18	2:03	192	42	180	126	1.09	140	132
19	1:07	184	51	188	201	1.41	148	144
20	2:53	184	41	184	167	1.15	160	144

RAW DATA (Continued)

Subject Number	Time on Treadmill Walk (30% Grade, 4 mph) (Min. &Sec.)	Max. H.R. after Treadmill Walk (bpm)	Bicycle Test (Sec. for 85 Rev/4 Resistance Units)	Max. H.R. after Bicycle Test (bpm)	Max. Breathing Test (Liters per min.)	Step Running Test (Hundreths of Sec.)	Recovery H.R. for one min. after Treadmill Walk Test (bpm)	Recovery H.R. for one min. after Bicycle Test (bpm)
21	1:30	188	62	176	161	1.28	160	146
22	2:11	200	36	176	233	1.12	168	148
23	2:24	192	44	188	190	1.11	164	156
24	3:31	212	49	208	164	1.05	192	156
25	1:56	188	43	188	152	1.11	160	148
26	3:01	188	44	172	172	1.23	160	136
27	1:53	184	45	176	089	1.24	140	148
28	1:57	192	51	184	167	1.20	172	152
29	1:33	188	46	180	112	1.17	152	144
30	1:48	184	45	168	124	1.21	150	120
31	1:20	196	54	170	163	1.36	156	150
32	1:27	192	51	184	115	1.18	164	152
33	1:42	184	43	184	191	1.15	158	164
34	2:05	210	50	188	158	1.26	148	136
35	5:35	180	30	180	199	1.06	144	120
36	2:13	188	39	192	213	1.25	156	144
37	3:53	188	44	176	167	1.18	144	136
38	2:01	188	42	188	187	1.11	164	152
39	2:17	184	49	176	167	1.25	152	128
40	1:35	188	50	176	121	1.28	158	140

APPENDIX B

Example of Calculation of Maximal Breathing Capacity*

Initial Kymograph Reading = 720
Final Kymograph Reading =-245
Difference 475

475 x 133.2 (constant bell factor of Gasometer)
= 63270 cc for 15 sec.

63270 x 4 = 253080. cc. per minute or 253.08 liters per minute (cc divided by 1000 = liters)

253.08 x 1.08 (temperature correction factor)
= 273 liters per minute**

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*Directions for operating Collins Chain-Compensated Gasometers 120-350-600 Liter sizes. Warren E. Collins, Inc., 555 Huntington Avenue, Boston 15, Massachusetts

**This was the largest M.B.C. score in the present study.

VITA

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