THE EFFECT OF INTERVAL TRAINING
ON OXYGEN DEBT

By

HAYRETTIN DAYLAN

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ON OXYGEN DEBT

Thesis Approved:

Aix B. Harrison
Thesis Advisor

L. M. Bridges

Betty Abercrombie

Norman N Durham
Dean of Graduate College

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CHAPTER I

THE RESEARCH PROBLEM

Introduction

There are few data available concerning the relationship between estimates of maximal oxygen debt in combination with maximum VO_2 in predicting maximal work (performance) of the individual. It might seem that since the major portion of the oxygen requirement of an endurance task is paid by current O_2 consumption, oxygen debt would be excluded as an important factor.

In short term maximal work, for example a 100 yard dash, the oxygen requirement is above the aerobic power, is predominately paid for by the surplus O_2 intake during recovery. Therefore, the faster an individual runs the dash the more O_2 debt he should accumulate (1). Energy for short term maximum effort is obtained in various proportions from aerobic and anaerobic metabolic processes. The amount of energy obtained by anaerobic processes cannot be measured directly. It can be approximated by measuring the amount that the metabolism is increased above resting values following exercise (oxygen debt) and by measuring the difference between resting blood lactate and the highest value observed during or after exercise. Oxygen debt and blood lactate concentration provide estimates of different aspects of the energy obtained from anaerobic sources (2).

The metabolic processes that supply the energy needed of muscle contraction ordinarily take place in the presence of adequate O_2 to oxidize the carbohydrate sources of energy completely to CO_2 and H_2O. This constitutes aerobic muscle activity which in general is exercise such that the intensity is low enough that it can be carried on for at least five minutes or longer. On the other hand if the intensity of exercise is very high so that exhaustion insues within one to two minutes or less, the energy must be supplied largely by anaerobic processes (without O_2), because O_2 cannot be transported via the lungs and cardiovascular system rapidly enough to supply such a demand (3).

The term oxygen debt (O_2 debt) was first introduced by A. V. Hill to describe the post-exercise elevation in VO_2 above the pre-exercise level. The possible cause and the magnitude of O_2 debt have been extensively examined following both submaximal and maximal exercise (4). A wide range of values have been observed for O_2 debt following maximal exercise; these findings have often been attributed to such factors as differences in testing protocols, methodology, and fitness levels of the subjects. Surprisingly, the variability of this measurement within a single individual has not been clearly established.

Through the research of Hill, Margaria, and other early leaders (5), a concept of two separate stages of oxygen debt was established; an alactacid stage and a lactic acid stage. Light to moderate work loads are performed during the alactacid stage of oxygen debt, and steady state is maintained during this perios. The alactacid debt occurs at the initial phase of work with oxygen debts of up to two and one-half liters, while heart rates were not elevated higher than 160 beats per minute. The stage is accompanied by increases of lactic acid in the muscle tissue, but not in the blood stream, and the debt is quickly repaid, generally within three to five minutes.

During the lactic acid stage of oxygen debt, there is an accumulation of excessive lactic acid in the blood stream and this is linearly related to the amount of work performed. Heart rates are elevated to above 180 beats per minute and the removal of excessive lactic acid during recovery is much slower, taking from 15 to 90 minutes. The calculation of maximum oxygen debt may appear to be a simple matter to the casual observer; however, large differences exist between maximum theoretical values for the oxygen debt following muscular exercise (three to five liters) and some experimentally determined values (12-20 liters). The wide range of maximal oxygen debts that have been reported is of major concern. Values ranging from 12-20 liters have been reported for human subjects.

We know that during vigorous exercise, the blood circulates more rapidly to the muscle supplying the cells with oxygen and nutrition and removing waste products. The heart activity is accelerated, exercising and strengthening its own fibers, while it is pumping the blood. The work of all muscles is affected by the efficience of the heart. If a muscle does its job well, the quality of the contractions is improved through such factors as: fuel being made available in greater amounts because of the improved circulation of blood through the muscle; better coordination of the individual muscle fibers; and more complete use of all muscle fibers. Therefore, it is easy to see that the cardiovascular system performs a vital service in the performance of sustained muscular activity (6). This is especially true when the exercise is vigorous enough to cause an individual to reach his maximum oxygen debt. It is not only dependant upon the strength of the muscles involved in the activity but must rely greatly on the effective functioning of the circulatory system.

The methods known for assessing or evaluating physical efficiency may be classified as field or laboratory tests. Nagle, Naughton, and Balke believe that physical fitness is most accurately assessed in the laboratory by making physiological measurements on a motor-driven treadmill or riding a stationary bicycle ergometer (7).

Most of the tests being used today are aerobic. The most widely used tests are: 1) Balke's Treadmill Test, 2) Balke and Cooper's Fifteen and Twelve Minute Running Tests, 3) Astrands's Bicycle Ergometer Test and 4) Step Tests (Harvard Step Test and Tuttle Pulse-ratio). The general public is most concerned with these types of testing methods because they are an evaluation of an individual's ability to function in normal day to day living (8).

This study is concerned with an anaerobic test that will push the individual to complete exhaustion and to his maximal oxygen debt capacity. The oxygen debt test is the only way we have of measuring an individual's ability to perform under very strenuous energy type conditions. There has been no wide spread demand for a test of maximal oxygen debt in the past, and as a result, very few have been developed.

Statement of the Problem

The present study was designed to determine the effect of interval training on oxygen debt capacity of varsity track men.

Subproblems

1. To compare the means of maximum VO_2 both pre-training and post-training.

2. To compare the means of resting heart beat both pre-training and post-training.

3. To compare the means of maximum heart beat both pre-training and post-training.

Hypothesis

The author proposed the Null-hypothesis indicating no significant differences between pre- and post-training means of all measures at the .05 level of confidence.

Assumptions

Assumptions of the study were as follows:

1. The subjects gave a maximum effort when they performed on the all-out treadmill run.
2. The author and lab assistant had the ability to properly administer the treadmill test.
3. The subjects were equally motivated to give a maximum effort.
4. The gas analyzers were properly calibrated.
5. The treadmill running test was capable of requiring the subjects to work to a maximum oxygen uptake.

Limitations

The following restrictions were considered to be limitations of the study:

1. The sample was small and non-random.
2. The author was unable to eliminate the subjects emotional responses such as nervousness and apprehension which could affect the subjects' results.

Delimitation

The study was limited to varsity track runners at Oklahoma State University.

Need for this Study

The actual need for this study was to conduct an interval training program for Oklahoma State University varsity track men. The author needed to apply this interval training to the eleven volunteers from the track team. The author was mainly concerned with oxygen debt, therefore he tested all of the subjects before starting to use an interval training program (pre-training test- September 10, 1978). Then the author applied this interval training program for twenty weeks. After this period, he retested the subjects (post-training test- February 1, 1979). In this study the author compared the pre-training test results (oxygen debt) with the post-training test results (oxygen debt) in order to find out whether interval training has an effect on the subjects oxygen debt capacity.

Definition of Terms

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

Anaerobic - The process of using energy in the absence (without) of oxygen.

Oxygen Uptake - (VO_2) The amount of oxygen taken into the lungs, transported to, and utilized by the tissues.

Oxygen Debt - This is defined as the amount of O_2 taken up in excess of the resting value during the recovery period. For this study the recovery period was restricted to thirty minutes.

Description of Instruments

Quinton Motorized Treadmill: An apparatus with continuously moving belts which can be adjusted to run at varying speeds and can be adjusted to varying inclines (Model 24-72, Seattle, Washington).

Electrode: Two disc shaped devices attached to the skin surface on either side of the heart. These electrodes transduce the electrical impulses of the heart into electrical signals.

Douglas Bag: A plastic bag used to keep the thirty minute recovery air expired.

Biotelemetry Transmitter: A battery powered device which sends electrical signals from the electrodes by telemetry to a biotelemetry receiver (Model FM 1100-E2; E & M Instrument Co., Inc., Houston, Texas).

Telemetry: A method by which a signal can be sent by radio waves from a battery powered transmitter to a receiver.

Biotelemetry Receiver: An instrument which receives electrical signals from the biotelemetry transmitter by telemetry and sends them to the physiograph machine (Model FM 1100-7, E & M Instrument Co., Inc., Houston, Texas).

Narco Physiograph Machine: A multi-channel instrument which records and monitors electrical signals from the biotelemetry receiver (Type PMR-4A, Six Channels; E & M Instrument Co., Inc., Houston, Texas).

CD4 Dry Gas Meter: An instrument used to measure the amount of gas passed through it (Instrumentation Associates, Inc., New York, New York).

Beckman Oxygen Analyzer: Measures the O_2 content of gas sample, (OM-14).

Pulmo Analyzer Godart: Measure O_2 and CO_2 content of a gas sample

Tissot tank: A gas meter, especially made to measure expired air.

CHAPTER II

REVIEW OF RELATED LITERATURE

In 1922, Hill and Lupton (9) coined the term "oxygen debt" to describe the amount of oxygen utilized, above the resting level, during the recovery period. Since their work, much interest has been shown in the oxygen debt and its components. Margaria, Edwards, and Dill (10) and Henry and DeMoor (11) found that the oxygen debt could be explained in total alactacid and lactacid components. It is well established that the lactacid component represents the energy released during anaerobic glycolysis with the subsequent formation of lactic acid (12); however, the alactacid component is not so clearly defined. The alactacid component has been said to represent the oxygen eauivalent for repayment of the following processes:

1. refill the myoglobin stores
2. replenish the dissolved oxygen in tissue fluids
3. regenerate oxyhemoglobin
4. provide for increased temperature and adrenaline output
5. supply oxygen for increased ventilation and elevated heart rates
6. reestablish the "normal" ATP and creatine phosphate levels
7. tissue repair
8. ion redistribution
9. metabolic turnover- other than lactic acid, i.e. lipid turnover (13)

Knuttgen (14) has further increased the complexity of information by demonstrating that the fast and slow components of the recovery oxygen uptake curve are not directly related to the alactacid and lactacid components of the oxygen debt.

It has been shown by Margaria, Edwards, and Dill (10) that the oxygen debt contraction and payment as an effect of exercise cannot be explained solely by lactic acid (LA) formation. These authors point out that the payment of the oxygen debt during recovery from muscular exercise is not related simply to lactic acid disappearance from the blood. In fact, a) in light exercise an oxygen debt is built up without any LA increase taking place in the blood and this debt is paid during recovery; the half-time of this process which appears to be an exponential function of time is about 30 seconds; and b) during recovery from an exhausting exercise, the oxygen debt payment and the lactic acid disappearance from blood have a substantially different time course.

A detailed analysis of the oxygen consumption curve during recovery led these authors to the conlcusion that the oxygen debt payment is made up of two distinct processes to which the names of "alactacid" and "lactacid" oxygen debt were given. The payment of the lactic acid disappearance from the body or from the blood is a much slower process than that of the "alactacid" fraction; the half-reaction time being 15 minutes.

From a quantitive study of the two processes, oxygen consumption and lactic acid disappearance from the body during recovery, the combustion coefficient of lactic acid (the ratio of LA burned divided by the total LA removed) could be calculated, and this was found to be not greater than about 1:10 (15).

A large number of investigations have been undertaken in order to solve the problems concerning the metabolic events occuring during muscular contraction. Ever since the work of Fletcher and Hopkins (16) in 1907 and others, it has been generally accepted that the energy required for muscular contraction came from the breakdown of glycogen (the storage form for carbohydrates in the muscle cells) to lactic acid under anaerobic conditions. However, it was shown by Lundsgaard (17) in 1930 that isolated muscles, poisoned with iodocetate were able to contract without lactic acid formation.

Recently, a large number of investigations have been performed in order to clarify the exact pathways of the energy metabolism, i.e., the transformation of chemical into mechanical energy, the enzymes involved, etc. (18); Davis and co-workers (19) were able to poison the enzyme phosphocreatinkinose in the muscle. Under these conditions phosphocreatine did not disappear. However, adenosinetriphosphate (ATP) did disappear with the simultaneous formation of adenosinediphosphate (ADP) and inorganic phosphate.

Not all of the energy costs of work can be provided by aerobic processes during the actual work period. Oxygen uptake increases during the first minutes of exercise (submaximal work load) to a "steady state" of consumption at which point the oxygen uptake corresponds to the energy demand of the tissues. The lack of oxygen in the initial period is referred to as the oxygen deficit. This delay in respiratory oxygen uptake could be caused by the relatively sluggish response of the circulatory system. The oxygen debt will depend upon the work time, when the work load is constant. Oxygen uptake and oxygen debt increase with the increase in time of the work. Oxygen uptake rises to a maximal level and stays there during the rest of the work period. Oxygen debt and blood lactate concentration on the other hand rise during the whole work period. If the work is stopped after one minute, values for oxygen debt and blood lactate concentrations will be lower than after a two or three minute work period. About 3 to 4 liters of the extra oxygen taken up after the cessation of work do not take part in the elimination of lactic acid. The remaining oxygen uptake may be utilized to remove the lactic acid produced during the work period. This part of the oxygen debt is referred to as the lactacid oxygen debt (20).

A study to determine relationships in terms of time changes in oxygen consumption and oxygen debt was conducted by Schneider and his associates (21). Oxygen debt following the exercise periods varied with the intensity and oxygen requirement of the work but did not vary with duration of work performed at a given rate. The oxygen debt was neither repaid nor increased during work even though 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.

Lactic acid is a very important ingredient in the economy of the muscle. Its oxidation provides the power required to do external work, and it appears to be derived from the glycogen stored. When a man's muscles are exercised at a constant speed, the lactic acid content of the active muscle increases gradually from its resting minimum. The rise in lactic acid content increases the rate of oxidation, and if the oxygen supply is adequate, a steady state is reached in which the rate of lactic acid production is balanced by the rate of its oxidative removal. Therefore, its concentration remains constant in the muscle as long as exercise of that speed is maintained. If the severity of the exercise becomes too great, the supply of oxygen cannot cope with the production of lactic acid, and exhaustion rapidly sets in. It is under these conditions that oxygen debt occurs.

There are studies that indicate that while an individual's anaerobic capacity is largely inherited, it is also trainable. Therefore, the effect of training an anaerobic performance would be of interest to physical educators, coaches, and athletes who are involved with work that produces oxygen debt. The following studies indicate that anaerobic capacity can be increased through training.

Maximal oxygen consumption, oxygen debt, lactic acid production, heart rate, and work output were measured on four male subjects by Davies and others (22). Oxygen debt repayment occurred more rapidly following training. Heart rates were lower and recovery more rapid for identical work loads.

Robinson and Harmon (23) showed evidence that as physical work capacity was improved by training the blood lactate increased less in response to a given amount of work and reached higher concentrations at the end of exhausting work. After 14 men trained for six months Knehr, Dill, and Neufeld (24) found the maximum oxygen uptake had increased 7% and the blood lactate concentration after maximum work increased 18%. The oxygen debt increased 5-6% and the physical work capacity 60%.

The Effect of Training on Physical Performance

Fifteen subjects from the University of Idaho cross country squad were randomly divided into a control group and an experimental group (25). The subjects were tested on three occasions at five week intervals throughout the competitive season. Tests administered were treadmill, max. VO_2, 440 yard run, three minute run, and selected strength measures. In addition to regular training sessions for all subjects, the experimental group was required to participate in a supplement endurance weight training program. The results indicated that there were increases in maximum VO_2, three minute run performance, and total strength in both groups. These improvements occurred during the first five weeks of the season. The supplemental endurance weight program had no significant effect on distance running performance. A highly significant correlation was found between maximum VO_2 ml/kg/min. and three minute run performance. Distance running performance was not related to either 440 yard performance or a composite of selected strength measures.

In another study, the relationship between estimates of maximal oxygen debt, aerobic power, 100 yard sprints, and two mile run times was studied (26). The estimated maximal oxygen debt averaged 4.89 liters net, maximum VO_2 intake was 3.34 l/min., two mile time was 13.73 minutes, and the 100 yard sprint time was 12.4 seconds. The multiple correlation to predict running performance was .57, using oxygen debt and maximum VO_2 and adding the body weight variable thus increasing the correlation only slightly to .58. For the 100 yard sprint, the correlation was r=.01 with oxygen debt, .10 with maximum VO_2; the multiple correlation to predict 100 yard sprint time of .20 was not improved by adding body weight. Evidently effective prediction of individuals difference in two mile running and sprint performance requires more than measured values of oxygen debt and aerobic power (max VO_2).

Another study was designed to determine the time relations of changes in O_2 consumption, O_2 debt, blood lactate, and "excess lactate" during aerobic work and recovery (27). Experiments were carried out in which men worked on the treadmill for periods of 3, 8, and 14 minutes and in some experiments for 25 minutes. Oxygen debts determined following these work periods (3-25 min.) varied with the intensity and O_2 requirement of the work, but did not vary with the duration of work performed at a given rate. This was true in a nonathletic man and in a trained distance runner. The constancy of the O_2 consumption and of the respiratory O_2 debt after the third minute of constant aerobic work, and their direct relations to each other and to the rate of work, suggests that the levels of O_2 consumption in the work is dependent on the maintenance of a constant O_2 debt as the work is continued. The lag in consumption in the early minutes of exercise appears to be more directly dependent upon the time required to develop an O_2 need, and thus to prepare the tissues to accept O_2, than on a lag in the O_2 supplied by the circulatory and respiratory systems.

In another study, nine experienced middle distance runners completed three experimental runs of equal distance and duration on a motor driven treadmill (28). Each run varied according to pace (steady, fast-slow-fast, and slow-fast), with the individual order of runs rotated to prevent bias in the report. Heart rate and oxygen consumption measures were taken during rest, exercise, and a 30 minute recovery period. Oxygen consumption values for the 30-90 minute recovery period were extrapolated from earlier measured recovery values. Analysis of data indicated that there were no significant differences among the three pace plans in net oxygen intake during the runs. However, the total oxygen debt values for the steady pace was lower than that for either the fast-slow-fast or the slow-fast pace.

In three experiments a man ran on the treadmill at 6.84 yds/sec. for the exact times of one minute, two minutes, and 2.58 minutes, respectively (29). In previous trial runs this speed was found to exhaust the runner in 2.58 minutes. For each run his O_2 intake and O_2 debt were determined and samples of venous blood drawn before and 4 minutes after work were analyzed for lactic acid. The runner's O_2 requirement was found to decrease in the second minute of the 2.58 minute run at a constant speed and then to increase markedly in the last half minute as he approached exhaustion. The rate of accumulation of lactic acid was also greatly accelerated in the last half minute of the run. These results are confirmed by similar experiments on two other subjects. In other experiments it was found that a runner who was exhausted in 3.37 minutes of running at a constant speed of 6.84 yds/sec. could cover the same distance (1382 yards) in the same total time with lower O_2 requirement and less elevation of lactic acid if he ran the first 2.37 minutes at 6.63 yds/sec. and the last minute at 7.33 yds/sec.; whereas, if he ran the first minute at 7.33 yds/sec. and the last 2.37 minutes at 6.63 yds/sec. both his O_2 requirement and blood lactate were higher than when he ran at a constant speed. It is clear from the data that in order to run a given middle distance race in minimum time the runner should follow a pace which will delay until near the end of the race the sudden change in physiological state in which the energy cost of running and the development of fatigue are so greatly accelerated. He 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 O_2 debt to the maximum.

A study by Graham and Andrews (30) was designed to assess the contribution of the intraindividual variability of oxygen debt to the range (65-248 ml/kg) reported for human subjects following exercise which required maximal oxygen uptake. The intraindividual variability for O_2 debt was greater than that for maximum VO_2, (p. 0.01), the mean individual coefficients of variation being 21.3 and 9.0% respectively. The cross country sprint and track runners demonstrated graded maximum VO_2 values, (p. 0.05) than the control group, but no signigicant differences could be shown between any one of the groups for O_2 debt. Thus training did not appear to be a major factor contributing to the diversity seen in O_2 debts.

Aerobic and anaerobic metabolism during a short exhaustive run was studied in eight males before and after training (31). The short exhaustive run was performed on a treadmill at a speed of 8 mph and a grade of 20%. Run times ranged from 36 to 66 seconds. A six week training program of interval sprints of 220 yards and distance runs of 2 miles were designed to stress the capacity for both aerobic and anaerobic metabolism. The training program resulted in a 23% increase in run time for the short exhaustive run. With training no change was observed in the oxygen uptake during the first 30 seconds of the short exhaustive run. However, after the initial 30 second period of metabolic adjustment, the oxygen uptake during the remainder of the run was higher after training. Compared to pre-training test results, post-test training results showed that there was a 9% increase in oxygen debt and a 17% increase in blood lactate concentration. The extra energy needed for the longer post-training run could be attributed to the increased oxygen uptake during the final stages of the run, to increased glycolysis and to an increased capacity to incur oxygen debt.

S. Robinson and P. M. Harmon (32) conducted an experiment on the "effect of training and of gelatin on muscular work". Nine non-athletic men were trained for running during a period of 26 weeks. Six of them took 60 grams of gelatin a day from the 9th through the 15th week of training and three took the same amount of gelatin from the 15th through the 21st week.

Changes associated with training were: consistent improvement in timed races on the track; an average increase of 16% in the maximal O_2 consumption during exhausting work; an increase in the lactic acid mechanism for contracting an O_2 debt; an improvement of 8% in efficiency in running; and a slight increase in the excretion of creatinine during the first part of the training period.

The training had no effect on the basal metabolism and caused only a slight rise of efficiency in grade walking.

None of the above functions were affected by gelatin. Neither the "alactacid oxygen debt" not the lactic acid mechanism was affected by gelatin.

C.A. Knehr, D.B. Dill, and William Neufeld (33) conducted an experiment about "Training and Its Effects on Man at Rest and at Work". A group of fourteen subjects followed a training regime for middle distance running over a period of six months. The men were studied before and during the period at rest and while doing two grades of work on a motor driven treadmill.

The training regime was accompanied by a slight increase in weight, a decrease in resting pulse rate of five beats per minute, a slight decline in the respiratory rate and volume, and a slight increase in plasma chloride. In addition an increase in efficiency of grade walking was observed.

In exhausting work there was an increased capacity for supplying oxygen to tissues and greater utilization of anaerobic energy reserves. The work increment unaccounted for by these alterations presumably results from a more economical organization of bodily functions. The increased capacity for accumulating lactic acid that is developed during training, and the notably high lactate levels attained by first class athletes points to this determination as a useful index to cardiovascular fitness.

In exhausting activity, such as in competitive sports and in war, the vigor and extent of exercise are circumscribed by the limits of the physiological functions involved. We know that at a given age and under fixed conditions, the heart rate cannot be pushed beyond a certain value.

At any given time the capacity for supplying oxygen to the tissues is strictly limited. The individual will work anaerobically until a tolerable limit of oxygen debt and concentration of lactic acid is reached. Severe prolonged work may be limited by the stores of carbohydrates (34).

Summary of Related Literature

A.V. Hill and Lupton were early researchers in the study of anaerobic work, coined the term "Oxygen Debt" in 1922. Through the research of Hill and other early leaders (35), the concept of two seperate stages of oxygen debt was established; these stages were an alactacid stage and a lactic acid stage.

Increases in maximum oxygen uptake, oxygen debt, and blood lactate concentration have been associated with significant increases in maximum performance following a training program (36-37). Robinson and Harmon (38) showed evidence that as physical work capacity was improved by training the blood lactate increased less in response to a given amount of work and reached higher concentrations at the end of exhausting work. After 14 men trained for six months Knehr, Dill, and Neufeld (39) found the maximum oxygen uptake had increased 7% and the blood lactate concentration after maximum work increased 18%. The oxygen debt increased 5-6% and the physical work capacity 60%.

It has long been known that a trained individual has a much lower rate of rise in lactic acid than the untrained individual working at the same load. Until recently it has been assumed that this was due to better O_2 transport in the trained individual.

CHAPTER III

METHODS AND PROCEDURES

Experimental Design

Eleven volunteers out of twenty-four Oklahoma State University varsity track team members were tested in the Oklahoma State Physiology of Exercise Laboratory, for oxygen debt, maximum VO_2, maximum heart rate, and resting oxygen uptake. Subjects were tested at the beginning of the interval training program (pre-training test). The training program consisted of interval training; (Appendix C). After twenty weeks of conditioning the subjects were retested (post-training).

After completing the pre-testing it was decided to change the post-testing procedure for the following reasons:

1. During the pre-test each subject spent two hours for one evaluation.

2. Each subject complained about the time.

3. Changes were made in the speed and elevations of the treadmill so as to take less time for the entire test. It was assumed that these changes would not affect the final results.

Test Procedure

1. Subjects reported to the physiology of exercise laboratory.

2. The subjects breathed into the Tissot tank for three minutes to determine a resting minute ventilation and oxygen intake.

3. Telemetry equipment was attached to the subjects for monitoring.

4. Each subject ran on the treadmill, using the following schedule:

Pre-training test-

a) All subjects started at 7 mph at 3% elevation for five minutes.

b) Speed was increased to 8.5 mph at 5% elevation for three minutes.

c) Speed remained at 8.5 mph with elevation at 8.5% for ten minutes.

d) Elevation was raised to 10% and speed remained at 8.5 mph until the subject became exhausted.

e) Subjects gave a signal when they felt that they could go only one more minute. After the signal, the subjects expired air was collected in the Tissot tank for thirty seconds. The subject then continued as long as possible.

f) Subjects were helped off of the treadmill and seated on a chair. They breathed through the CD4 gas meter into a Douglas bag for a thirty minute recovery period.

g) Maximum VO_2. oxygen debt, maximum heart beat, and resting oxygen intake were determined from the expired air following the procedure outlined in Ricci (40). Gas analyses were made for CO_2 on a Godart Pulmo-analyzer and for oxygen on a Beckman Oxygen analyzer.

Post-training test-

a) All subjects started at 7 mph at 0% elevation for five minutes or when the subject reached 150 beats per minute (warm-up period).

b) Speed was increased to 8.5 mph at 8.5% elevation for three minutes.

c) Speed was increased to 10 mph at 8.5% elevation until exhaustion.

d) Subjects gave a signal when they felt that they could go only one more minute. After the signal, the subjects' expired air was collected in the Tissot tank for thirty seconds. The subject then continued as long as possible.

e) Subjects were helped off of the treadmill and seated on a chair. They breathed through the CD4 gas meter into a Douglas bag for a thirty minute recovery period.

f and g) same as pre-testing procedure.

h) In addition to those results, the author recorded the subjects' age, weight, and height (Appendix B).

CHAPTER IV

RESULTS

The author has attempted to determine if an interval training program would improve anaerobic performance of track athletes.

Table I presents the means of the subjects raw scores on the various measurements taken during pre-testing. Table II presents the means of the subjects' raw scores on the various measurements taken during post-testing. And Table III presents the differences betweeen the post-test and the pre-test means.

The mean maximum oxygen debt produced during pre-test was 9.49 liters (Table I). The range was from 5.71 liters to 13.82 liters. During the post-test the mean was 10.09 liters (Table II), and the range was from 5.7 liters to 13.93 liters. The mean maximum VO_2 produced during pre-test was 64.04 ml/kg/min. and the range was from 55 ml/kg/min. to 80 ml/kg/min. During the post-test the mean was 66.62 ml/kg/min. and the range was from 41.08 ml/kg/min. to 86 ml/kg/min. The mean maximum heart rate during pre-test was 192 beats/min., and the range was from 180 to 210 beats/min. The mean maximum heart rate during post-test was 190 beats/min., and the range was from 180 to 204 beats/min.

Several means related to the rate of oxygen debt and maximum VO_2 were recorded. Resting O_2, resting ventilation, and maximum ventilation. The mean of resting O_2 was .322 during the pre-test and .422 during the post-test. The mean of resting ventilation was 11.55 l/m during the pre-test and 11.88 l/min. during the post-test. The mean on maximum ventila-

TABLE I

PRE-TEST MEANS

	Age	Weight (lbs)	Resting heart beat	Maximum heart beat	Resting O_2 l/min.	Max VO_2 ml/kg/min.	Resting vent.	Maximum vent.	Maximum O_2 debt
Mean	19.6	154.16	60.18	192	.32	64.04	11.55	128.37	9.49

TABLE II

POST-TEST MEANS

	Age	Weight (lbs)	Resting heart beat	Maximum heart beat	Resting O_2 l/min.	Max VO_2 ml/kg/min.	Resting vent.	Maximum vent.	Maximum O_2 debt
Mean	19.6	153.12	61.0	190	.42	66.62	11.88	129.99	10.09

TABLE III

DIFFERENCES BETWEEN PRE- AND POST-TEST MEANS

	Age	Weight (lbs)	Resting heart rate	Maximum heart rate	Resting O_2 l/min.	Max VO_2 ml/kg/min.	Resting vent.	Maximum vent.	Maximum O_2 debt
Differences	0	-1.04	+ .82	- 2.0	+ .10	+2.58	+ .33	+ 1.62	+ .60

tion was 128.27 l/min. during the pre-test and 129.99 l/min. during the post-test.

Statistical Analysis

The pre- and post-test means of each variable were evaluated with a t-ratio to test for significance of difference between means. The Dwyer's Single Computational Formula for t-ratio between correlated scores was used. Values for t on oxygen debt, (Appendix A-1), maximum VO_2 (Appendix A-2), maximum heart beat (Appendix A-3), and resting O_2 (Appendix A-4) were .81, .25, .56, and 2.266 respectively. A t-value of 1.96 was needed to be signigicant at the five percent level of confidence. The Null hypothesis was accepted in the first three of the above cases, and Null hypothesis was rejected in the fourth case becasue it had a t-value of 2.266 which is a significant difference at the five percent level.

Discussion

The treadmill was employed in these experiments because it places greater stress on O_2 transport system as a whole, thus evoking a higher VO_2 than the bicycle ergometer. Moreover, one might expect the measurements to be less affected by familiarization with this testing apparatus since it involves a more common skill than running or jogging outside (41).

Because the present study was concerned with the variation in maximal functions during exercise, it was important to establish that each subject did in fact reach maximum oxygen debt. Mainly four criteria have been tested in this investigation. These are O_2 debt, maximum VO_2, maximum heart beat, and resting O_2. All subjects in the present study reached their maximum effort during pre-testing and post-testing. The training program had no effect on the subjects' O_2 debt.

The author has observed that the twenty week interval training program did not produce any significant difference. The t-values in this study were .81 for O_2 debt, .25 for maximum VO_2, .56 for maximum heart beat, and 2.266 for resting O_2. Since a t-value of 1.96 is required for significance at the five percent level of confidence, the Null hypothesis was accepted in the first three cases, and in the fourth the Null hypothesis was rejected (resting O_2).

CHAPTER V

SUMMARY AND CONCLUSIONS

The importance of the oxygen debt capacity of an individual has been recognized by research physiologists for years. The purpose of this study was to find out the effect of interval training on oxygen debt. To achieve this purpose, treadmill tests that had been previously used to elicit oxygen debt were used in a pre-interval training test and in a post-interval training test. Measurements were made to see if the training program had any effect on oxygen debt. In addition to the oxygen debt, maximum heart beat, and resting O_2 were also observed.

Conclusions

From the evaluation of the data collected in this investigation, the following conclusions have been drawn:

1. The oxygen debt mean during the post maximum treadmill run was higher than the pre-test maximum treadmill run, but was not significant at five percent confidence level (Appendix A-1).

2. The mean maximum VO_2 volume during pre-treadmill tests was slightly lower than the mean VO_2 volume during the post maximum treadmill run, but was not significant at .05 confidence level (Appendix A-2).

3. The mean maximum heart rate during the post-treadmill test was slightly lower than during the pre-treadmill test, but was not significant at .05 confidence level (Appendix A-3).

4. The mean resting oxygen intake during post-testing was higher

than pre-test results, and there was a significant difference at .05 confidence level; therefore the Null hypothesis was rejected (Appendix A-4).

Recommendation

There is no question that is important to understand more about oxygen debt and its relationship to man's ability to do maximum type work. In order to effectively study this problem the following recommendations might be considered:

1. Use a greater number of subjects.
2. Utilize a shorter time for a training program; such as eight weeks.
3. Have a control group that does not train.
4. Pay the subjects.

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APPENDIXES

APPENDIX A

t RATIO CALCULATIONS

A

Dwyer's Single Computaional Formula

(t-ratio)

For evaluation of obtained differences between means of paired measures (or two measures on some group)

$$t = \frac{(EX)^2\ (N-1)}{NEX^2 - (EX)^2} \qquad \text{where: } x = x_1 - x_2$$

$$n = n_1 - n_2$$

To find "t", the author extracted the square root of t^2 and used a t-table.

A-1

EVALUATION OF O_2 DEBT BETWEEN THE RESULT OF

PRE-TRAINING AND POST-TRAINING TESTS

Subject	Pre-test (x_1)	Post-test (x_2)	Difference (x_1-x_2)	x^2
1	11.4	13.93	-2.53	6.4
2	6.3	7.21	- .8	.64
3	11.1	9.9	1.2	1.44
4	5.7	5.7	0	0
5	13.8	14.7	- .9	.81
6	5.91	6.0	- .09	.008
7	12.0	13.8	-1.8	3.24
8	12.0	7.32	4.68	21.90
9	7.2	7.8	- .6	.36
10	6.78	12.0	-5.22	27.24
11	12.15	12.6	- .45	.20
Mean	9.49	10.09	EX= -6.51	EX^2= 62.19

$$t^2 = \frac{(EX)^2\ (N-1)}{NEX^2 - (EX)^2} = \frac{(6.51)^2\ (11-1)}{11(62.19 - (6.51)^2} = \frac{423.80}{641.71}$$

t^2 = .66
t = .81

Probability at the .05 level of confidence= 1.96.

A-2

EVALUATION OF MAXIMUM VO_2 BETWEEN THE RESULT OF

PRE-TRAINING AND POST-TRAINING TESTS

Subject	Pre-test (x_1)	Post-test (x_2)	Difference (x_1-x_2)	x^2
1	4.42	5.06	- .64	.41
2	3.55	3.40	.15	.02
3	4.12	3.92	.20	.04
4	4.07	2.67	1.40	1.96
5	5.56	5.04	.52	.27
6	4.07	4.39	.32	.1
7	5.33	5.45	- .12	.01
8	5.25	4.86	.39	.15
9	4.59	5.0	- .41	.17
10	3.74	5.22	-1.48	2.19
11	4.55	5.55	-1.0	1.0
Mean	$\bar{x}_1$= 49.25	$\bar{x}_2$= 50.56	EX= - .67	EX^2= 6.32

$$t^2 = \frac{(EX)^2\ (N-1)}{NEX^2 - (EX)^2} = \frac{(-.67)^2\ (11-1)}{11\ (6.32) - (-.67)^2} = \frac{.448 \times 10}{69.52-.44} = \frac{4.5}{69.08}$$

t^2 = .065

t = .25

Probability at the .05 level of confidence = 1.96.

A-3

EVALUATION OF MAXIMUM HEART BEAT BETWEEN THE RESULT

OF PRE-TESTING AND POST-TRAINING TESTS

Subject	Pre-test (x_1)	Post-test (x_2)	Difference (x_1-x_2)	x^2
1	192	180	12	144
2	192	192	0	0
3	192	186	6	36
4	192	192	0	0
5	204	198	6	36
6	210	204	6	36
7	186	186	0	0
8	180	180	0	0
9	180	192	-12	144
10	204	204	0	0
11	180	186	- 6	36
Mean	$\bar{x}_1$= 192	$\bar{x}_2$= 190	EX= 12	EX^2= 432

$$t^2 = \frac{(EX)^2\ (N-1)}{NEX^2 - (EX)^2} = \frac{(12)^2\ (10)}{11(432) - (12)^2} = \frac{1440}{4608} = .31$$

t^2 = .31
t = .56

Probability at the .05 level of confidence = 1.96.

A-4

EVALUATION OF RESTING O_2 BETWEEN THE RESULT OF PRE-TRAINING AND POST-TRAINING TESTS

Subject	Pre-test (x_1)	Post-test (x_2)	Difference (x_1-x_2)	x^2
1	.31	.58	- .27	.07
2	.25	.46	- .21	.04
3	.30	.37	- .7	.49
4	.31	.43	- .12	.01
5	.38	.44	- .06	.003
6	.31	.63	- .32	.10
7	.37	.27	.10	.01
8	.33	.37	- .04	.002
9	.25	.26	- .01	.0001
10	.25	.48	- .23	.05
11	.49	.34	.15	.02
Mean	$\bar{x}_1$= .32	$\bar{x}_2$= .42	EX= -1.71	EX^2= .795

Evaluation using Dwyer's single computational formula

$$t^2 = \frac{(EX)^2\ (N-1)}{NEX^2 - (EX)^2} = \frac{(1.71)^2\ (11-1)}{11(.795) - (1.71)^2} = \frac{2.92 \times 10}{8.74 - 2.92} = \frac{29.2}{5.82}$$

t^2 = 5.137
t = 2.266

Probability at the .05 level of confidence = 1.96.

APPENDIX B

RAW DATA

TABLE IV

PRE-TRAINING TEST RESULTS

Subject	Age	Weight (lbs)	Height (in)	Resting heart beat	Maximum heart beat	Resting O_2 1/ min.	Max VO_2 ml/kg/min.	Resting ventilation 1/min.	Maximum vent. 1/ min.	Maximum O_2 debt
1	18	165	6'3"	72	192	.31	58.93	19.37	128.27	11.4
2	18	142	6'0"	54	192	.25	55.0	6.99	119.4	6.3
3	18	153	5'10"	60	192	.30	59.2	12.08	117.86	11.1
4	18	139	5'9"	54	192	.31	64.6	11.93	115.7	5.7
5	22	184.8	6'2"	60	204	.38	66.19	17.97	132.4	13.8
6	18	145	5'9"	66	210	.31	61.76	8.39	123.48	5.91
7	22	154	6'3"	48	186	.37	76.0	5.85	138.46	12.0
8	22	144	5'5"	54	180	.33	80.0	8.97	141.78	12.0
9	20	128	5'5"	48	180	.25	79.0	7.67	141.78	7.2
10	20	165	6'3"	66	204	.25	49.9	17.54	117.0	6.78
11	20	176	6'3"	60	180	.49	56.9	10.31	136.0	12.15
(total) E	216	1695.8		661.78	2121	3.52	704.48	127.07	1412.0	104.0
Mean	19.6	154.16		60.18	192	.32	64.04	11.55	128.37	9.49

TABLE V

POST-TRAINING TEST RESULTS

Subject	Age	Weight (lbs)	Height (in)	Resting heart beat	Maximum heart beat	Resting O_2 l/min.	Max VO_2 ml/kg/min.	Resting ventilation l/min.	Maximum vent. l/min.	Maximum O_2 debt
1	18	143	6'3"	78	180	.58	77.85	15.32	136.76	13.93
2	18	142	6'0"	66	192	.46	52.67	11.8	98.42	7.21
3	18	153	5'10"	66	186	.37	56.26	10.06	113.4	9.9
4	18	143	5'9"	60	192	.43	41.08	10.13	77.21	5.7
5	22	180.4	6'2"	72	198	.44	61.46	10.6	123.76	14.7
6	18	150	5'9"	72	204	.63	64.36	19.6	123.7	6.0
7	22	152	6'3"	48	186	.27	78.98	7.84	154.41	13.8
8	22	144	5'5"	54	180	.37	74.19	11.46	127.2	7.32
9	20	128	5'5"	48	192	.26	86.0	10.94	162.95	7.8
10	20	170	6'3"	60	204	.48	72.0	10.21	120.1	12.0
11	20	179	6'3"	48	186	.34	68.0	6.6	106	12.6
(total) E	216	1684.4		671	2090	4.62	732.85	130.77	1323.91	110.96
Mean	19.6	153.12		61	190	.42	66.62	11.88	129.99	10.09

APPENDIX C

TRAINING PROGRAM FOR

TWENTY WEEKS

Interval Training Program

1. First 4 weeks workout

Monday:

a.m. - 3 mile easy run
p.m. - proper warm-up
4 x 440 @ 80,78,76,74 sec.; 5 x 330 @ 47-46 sec.; 6 x 220 @ 32-28 sec.; 7 x 110 @ 16-14 sec.; 8 x 75 up and over 70% effort

Tuesday:

a.m. - 3 mile easy run
p.m. - 10 x 110 up and over; stadium step run (run every aisle, run up,jog down) 2 sets of south stadium
5 min. easy run for cool down

Wednesday:

a.m. - 3 mile easy run
p.m. - 6 x 440 @ 90-70 sec., walk 220 between them
5 x 330 @ 47-44 sec., walk 150 between them
4 x 220 @ 31-28 sec., walk 110 between them
10 x 75 up and over 70% effort, walk 50 yds. between them
finish with an easy 880 yd. run

Thursday:

a.m. - 3 mile easy run
p.m. - 1320 @ 60% effort; 880 @ 65%; 440 @ 70%; 220 @ 75%; 110 @ 80%; 75 @ 85%; and 50 @ 90%
weight training for 40 min. (dead lift, bench press, leg press) should not exceed 70% effort

Friday:

a.m. - 3 mile easy run
p.m. - rest for the weekend

2. Fifth through eighth week workout

Monday:

a.m. - 3 mile easy run

p.m. - 12 x 50 up and over; 10 x 75 up and over; 8 x 10 @ 70-85%
6 x 220 @ 70-85%; 4 x 330 @ 45-46 sec.; 1 x 440 @ 70 sec.
finish with an easy 880 yd. run

Tuesday:

10 min. warm-up (1 mile easy run)
6 x 550 @ 65%; 4 x 330 @ 70%; 2 x 110 @ 85%
weight training (dead lift @ 75%; bench press @ 75%; leg press @ 85%)

Wednesday:

a.m. - 3 mile easy run
p.m. - 6 x 330 @ 47-43 sec.; 7 x 220 @ 33-27 sec.; 8 x 110 @ 16-14 sec.; 9 x 75 up and over; 10 x 50 up and over; 880 easy run

Thursday:

20 x 110 up and over
stadium steps (run every aisle on one side of the stadium) -3 sets
finish the workout with 1 mile easy run

Friday:

a.m. - 3 mile easy run
p.m. - rest

3. Ninth through twelfth week workout

Monday:

12 min. run

Tuesday:

3 mile easy run
8 x 110 on 35^{0} hills (wald down the hill)
8 x 75 @ 85-90% effort (walk slowly back)

Wednesday:

10 min. warm-up; 10 min. stretching exercises
3 x 660 @ 1:45, 1:40, and 1:35 sec.; rest until the heart slows to 110 beats/min.
3 x 220 @ 28, 26, and 24 sec. (walk 220 between them)
3 x 110 @ 13, 12, and 11 sec. (walk 110 between them)
1 x 440 @ 90 sec.

Thursday:

2 mile easy run

4 x 220 on 35^{o} hill (easy- good- easy- good)
4 x 110 on 35^{o} hill (easy- good- easy- good)
4 x 75 on 35^{o} hill (easy- good- easy- good)

Friday:

4 mile easy run
weight training (dead lift @ 80%, leg press @ 85%, bench press @ 80% - 35 min.)

Saturday:

rest

4. Thirteenth through sixteenth week workout

Monday:

3 mile easy run
10 x 180 on 30^{o} hill (walk back down) @ 70% effort

Tuesday:

1 mile easy run; 10 min. stretching exercises
220 @ 30 sec.; 330 @ 45 sec.; 440 @ 65 sec.; 550 @ 120 sec.; 330 @ 45 sec.; 220 @ 28 sec.
weight training (dead lift @ 90%, bench press @ 85%, leg press @ 90%)

Wednesday:

2 mile easy run
2 x 440 on 30^{o} hill @ 70%
4 x 330 on 30^{o} hill @ 75%
4 x 220 on 30^{o} hill @ 80%
4 x 110 on 30^{o} hill @ 85%
finish with 1 mile easy run

Thursday:

1 mile easy run
660 @ 1:36 sec.; 440 @ 62 sec.; 330 @ 42 sec.; 220 @ 26 sec.; 150 @ 18 sec.; 110 @ 12 sec.
finish with 880 easy run

Friday:

4 to 6 mile long run
weight training (dead lift, bench press, leg press, push-pull)

Saturday:

rest

5. Seventeenth through twentieth week workout

Monday:

1 mile in and out (run the straight and walk the curve)
8 x 85 yds. high knees
3 x 440 @ 60, 58, 56 sec. (walk 220 between them)
3 x 330 @ 46, 44, 42 sec. (walk 220 between them)
3 x 220 @ 28, 26, 24 sec. (walk 150 between them)
3 x 110 @ 14, 13, 12 sec. (walk 110 between them)

Tuesday:

1 mile easy run; 10 min. stretching exercises
4 x 220 continuous relay (5 people) walk 660
4 x 110 continuous relay (5 people) walk 660
finish with 880 easy run

Wednesday:

1 mile easy run; 10 min. stretching exercises
5 x 110 @ 16, 15, 14, 13, 12 sec. (walk 110 between them)
5 x 220 @ 32, 30, 28, 26, 24 sec. (walk 220 between them)
3 x 330 @ 45, 44, 43 sec. (walk 220 between them)
2 x 440 @ 68, 66 sec. (walk 220 between them)
1 x 660- run the first 440 @ 80 sec. then pick up the last 220 @ 28-29 sec.

Thursday:

4 to 6 mile long run
weight training for 40 min. (dead lift, bench press, leg press, push-pull)

Friday:

1 mile easy run; 10 min. stretching exercises
1 x 330 @ 47 sec.; jog 220; run 110 @ 15 sec.; walk 330
1 x 220 @ 31 sec.; jog 110; run 110 @ 14 sec.; walk 220
1 x 110 @ 15 sec.; jog 110; run 110 @ 13 sec.
repeat all again

Saturday:

rest

VITA

Hayrettin Daylan

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF INTERVAL TRAINING ON OXYGEN DEBT

Major Field: Health, Physical Education and Recreation

Biographical:

Personal Data: Born in Nusaybin, Turkey, January 1, 1953, the son of Mr. and Mrs. Daylan.

Education: Graduated from Hasan Oglan Teacher Training School, Ankara, in 1971; received the Bachelor of Science in Secdary Education degree from Oklahoma State University with a major in Physical Education in 1977; completed requirement for Master of Science degree at Oklahoma State University in July, 1979.

Professional Experience: Taught second and third grades for one year, then went to Physical Education of Ankara for three semesters as an undergraduate student. After that, won a scholarship to come to Oklahoma State University. Walked on the varsity track team, and coached intramural volleyball. Presently assisting the Oklahoma State University varsity track coach and working at the Physiology of Exercise laboratory as a graduate assistant.