To the Graduate Council:

I am submitting herewith a dissertation written by Michael Kelly Stuart entitled "Changes in Muscular Efficiency in Long Distance Runners and Sprinters as the Intensity of Work Increases." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Education, with a major in Physical Education.

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CHANGES IN MUSCULAR EFFICIENCY IN LONG DISTANCE RUNNERS AND SPRINTERS AS THE INTENSITY OF WORK INCREASES

A Dissertation

Presented for the

Doctor of Education

Degree

The University of Tennessee, Knoxville

Michael Kelly Stuart

December 1977

1347039

DEDICATION

To my wife, Suzy. Without her love, help, understanding, and encouragement this would not have been possible.

To my mother, Mary. For giving so much of herself to me. She was always there when needed.

ACKNOWLEDGEMENTS

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ABSTRACT

On the basis of the literature it was concluded that there were differences between distance runners and sprinters in terms of muscle fiber type. Distance runners were found to possess predominatly slow twitch muscle fibers and sprinters were found to possess predominatly fast twitch muscle fibers. Through studies on isolated muscle, efficiency was shown to be less in fast twitch than slow twitch muscle. Recruitment of the less efficient fast twitch fibers with increases in work intensity was also shown to occur. It was believed that any efficiency differences between distance runners and sprinters might be explained on the basis of muscle fiber type.

The purpose of this study was to investigate changes in muscular efficiency (delta and work efficiency) in highly trained distance runners and sprinters as the intensity of work increases. Five distance runners and five sprinters volunteered to participate in the study.

Each subject rode a series of five randomized, absolute workloads on a Monarch bicycle ergometer. The workloads were ten minutes in duration. Two expired gas samples of two minutes duration were collected between minutes 6 and 10 of each test. $\dot{V}O_2$ was computed and used to calculate work and delta efficiency. Efficiency (delta and work) values were regressed on work rate (absolute and relative) for each group. The means of the regression lines for the distance runners and sprinters were tested for significant differences with a t-test. The caloric outputs at their respective work rates were plotted for each group.

The $\dot{V}O_2$ of unloaded pedaling was determined and, due to poor day to day reproducibility, was deemed unacceptable as a baseline correction factor for the work efficiency calculation. For each subject, a linear regression of caloric output on work rate was calculated. The Y intercept was used as a baseline for computing work efficiency.

Because of the complexity of establishing a baseline, it was concluded that work efficiency was not a practical method of efficiency calculation. Caloric output was slightly exponential with increasing work rate. Delta efficiency best represented the exponential relationship between caloric output and work rate. For distance runners and sprinters delta efficiency decreased with increasing work rate.

There was no significant difference ($P > .05$) between distance runners and sprinters in terms of work or delta efficiency. This was true at absolute and relative workloads.

The decreases in efficiency could not be ascribed to the recruitment of less efficient fast twitch fibers since no significant difference existed between the two groups.

It was proposed that unmeasured work done by the fixator muscles of the pelvis, back, and forearms might be a reason for the decreasing mechanical efficiency observed with increasing work rate.

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CHAPTER I

INTRODUCTION

Since the beginning of this century the concepts of mechanical efficiency have been explored in depth. Several methods for computing efficiency have been developed and employed by the many studies dealing with the topic. The most often used procedure has been the net efficiency calculation. That is, the caloric equivalent of the oxygen used at rest is subtracted from the caloric equivalent of the oxygen used during work. The result is then divided into the caloric equivalent of the actual physical work performed and multiplied by 100. The formula would be written:

$$\text{Efficiency} = \frac{\text{Caloric equivalent of Physical Work Performed x 100}}{\text{Caloric equivalent of } O_2 \text{ used during work - Caloric equivalent of } O_2 \text{ used at rest}}$$

Net efficiency was used by researchers almost exclusively until 1969 when Whipp and Wasserman (63) published their work dealing with work efficiency. They supported the method that uses the caloric equivalent of the oxygen cost of unloaded pedaling as the baseline in lieu of rest. The equation would be stated:

$$\text{Efficiency} = \frac{\text{Caloric equivalent of Physical Work Performed x 100}}{\text{Caloric equivalent of } O_2 \text{ used during work - Caloric equivalent of } O_2 \text{ used during unloaded pedaling}}$$

Perhaps the most appropriate means of computation is that of delta efficiency. Delta efficiency is calculated by simply subtracting a

low work rate from a high work rate to obtain the delta work accomplished per minute. This result is divided by the difference between the rate of energy used at the high and low work rates, respectively. The result is then multiplied by 100 and expressed as a percent.[1] Gaesser and Brooks (30) stated that the relationship between caloric output and work rate is essentially linear or slightly exponential. If a linear relationship exists, efficiency should remain constant with increasing workload. However, if the relationship is slightly exponential, efficiency will decrease with increasing workload. The delta efficiency calculation permits the investigator to measure any change in mechanical efficiency that may occur as the intensity of work increases. By employing the delta efficiency calculation it has been shown that as work rate is increased efficiency is decreased, even under aerobic conditions (30).

There may be several reasons for this efficiency decrease. The amount of unmeasured work may increase as work intensity increases. However, Henry and DeMoor (42) recorded an oxygen consumption of only 0.1 to 0.2 liters per minute for tensing the arms against the handlebars and pushing with the legs on the pedals so as to cause pressure against a back rest that had been attached to the bicycle seat. A decrease in efficiency could also be explained by the work of Gibbs and Gibson, and Wendt and Gibbs (32, 61). These authors reported that

---

[1] $\text{delta efficiency} = \frac{\text{delta work accomplished}}{\text{delta energy expended}}$

$= \frac{W}{E} \times 100$

slow twitch fibers in mammalian skeletal muscle were much more efficient than fast twitch fibers. Since there is a shift from slow twitch to fast twitch fibers as intensity of work increases (21, 36, 37), this would explain a decreasing mechanical efficiency.

To examine a relationship between fiber type and efficiency, subjects possessing predominantly slow twitch or fast twitch fibers would be required. According to Gollnick and his colleagues (19, 20, 34, 35) such a situation exists between highly trained distance runners and highly trained sprinters.

The purpose of this study was to examine the changes in muscular efficiency (delta efficiency and work efficiency) in highly trained distance runners and sprinters as the intensity of work increases.

Hypotheses

1. Efficiency (work or delta) will decrease as the intensity of work increases.

2. There will be a significant difference in efficiency between distance runners and sprinters at any given work rate expressed in absolute or relative terms.

Definitions

$\dot{V}O_2$ is a measure of the rate at which O_2 is used. It is expressed in liters per minute.

$\dot{V}CO_2$ is the rate at which CO_2 is produced. It is expressed in liters per minute.

The respiratory exchange ratio (R) = $\frac{\dot{V}CO_2}{\dot{V}O_2}$

Max $\dot{V}O_2$ is the maximum rate at which oxygen is used.

Distance runners are college track athletes who regularly compete in and train for running events of 5,000 meters or longer.

Sprinters are college track athletes who regularly compete in and train for sprint events of 400 meters or shorter.

Absolute workload represents the rate at which a given amount of work is done.

Relative workload is the fraction of a subject's max $\dot{V}O_2$ used to exercise at a specific work rate. This is calculated by $\dot{V}O_2 \div \dot{V}O_2$ max x 100 percent.

Mechanical or muscular efficiency is the ratio of energy expended to do a given amount of work to the actual work accomplished.

Kilopond meter is the work done moving a mass of one kilogram over a distance of one meter at normal acceleration of gravity.

Watt = 6.12 kilopond meters per minute.

calorie is the amount of heat required at a pressure of one atmosphere to raise the temperature of one gram of water one degree centigrade.

Kilocalorie = 1000 calories

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Efficiency of the intact human body requires that two factors be measured accurately: the work accomplished and the energy expended to do that work. The relationship of these two elements has been most successfully examined by using the bicycle ergometer as the instrument for measuring work and by using the oxygen consumption during work as a means of establishing energy expenditure. It is an accepted premise that at submaximal, steady state levels, the oxygen uptake is equivalent to, or a measure of, the energy requirement for the workload. The two values are then expressed:

$$\text{Efficiency} = \frac{\text{Work accomplished}}{\text{Energy expended}} \times 100$$

Early Studies

Benedict and Cathcart (8) were some of the first to measure efficiency by "modern methods" in 1913. It is interesting to note that Benedict and Cathcart utilized the gross efficiency, (no baseline correction is used in the denominator of the formula) net efficiency, work efficiency, and delta efficiency calculations. For net efficiency experiments the authors used a baseline correction of the caloric equivalent of the oxygen used at rest while lying on a couch and sitting on a bicycle ergometer. For the work efficiency

calculation the caloric equivalent of the oxygen used for no load pedaling was measured. This measurement was taken with the subject pedaling the bike with no load, and also with a motor moving the pedals of the bike while the subject rested his feet on the pedals. In the calculation of delta efficiency, two submaximal loads were selected as baselines and used in the delta computation. The mean net efficiency (baseline = caloric equivalent of oxygen used while seated on the bicycle ergometer) was 19.1 percent. The work efficiency calculation (baseline = the caloric equivalent of the oxygen used during unloaded pedaling without the motor) yielded a mean value of 30 percent. The low baseline (0.5 ampere) and high baseline (0.95 ampere) delta efficiencies were 27.4 percent and 32.6 percent respectively. All efficiency values given are for a single subject who was a trained cyclist. The high work efficiency reported was attributed to the establishment of the baseline correction. Benedict and Cathcart (8) state:

> In discussing the no load experiments it was pointed out that the subject found himself uncomfortable, with a tendency to either "race" or else to "back pedal." Owing to this tendency, there was unquestionably considerable muscular activity, particularly noticeable in the alterations in the tension on the sprocket-chain.

In their discussion of delta efficiency they said:

> Since under these conditions the increase in the metabolism can be readily compared with the increase in effective muscular work, it would appear as though this was a most advantageous method of comparison.

They further state:

> From a consideration of these various methods of computing the energy, it is obvious that there are grave difficulties in the way of securing a baseline which will embrace only the extraneous muscular motions incidental to riding with load upon which could be superimposed a definite amount of muscular exertion productive of external work. Certain it is that the various baselines we have considered - lying, sitting, and riding no load with and without the motor - fail to meet this requirement.

Benedict and Cathcart (8) also reported a decrease in efficiency as speed of movement increased.

In 1920 Campbell, Douglas, and Hobson (12) reported net efficiencies on one subject to be 24.2 percent and 23.5 percent at workloads of 115 watts and 173 watts respectively. The baseline correction was the energy cost of sitting on the bicycle ergometer. Net efficiency was also computed using "basal metabolism" as the baseline correction. That is, the energy cost of lying in bed immediately after waking was subtracted from the energy cost of riding a load. The efficiency values were then reduced to 23.4 percent and 23.0 percent. A work efficiency calculation using the same data raised the efficiencies to 28.4 percent for the 115 watt load and 25.9 percent for the 173 watt load. The above values are from experiments done on subject Douglas. Net efficiency using a baseline correction for sitting on the bike was also calculated for subject Hobson. He performed at 25.4 percent at 115 watts and 24.7 percent at 173 watts.

Effect of Speed on Efficiency

In 1923 Duffield and MacDonald (28) supported the work of Benedict and Cathcart when they demonstrated that at constant load work, muscular efficiency decreases as speed of movement increases. This was later substantiated by the efforts of Dickinson (27). However, Garry and Wishart (31) found a progressive rise in efficiency with increasing speed when the work efficiency calculation was used. These same authors reported an optimum pedal frequency of 52 rpm using gross efficiency. Any increase in speed at that point caused a decrease in gross efficiency. On the contrary, Gaesser and Brooks (30) report decreasing efficiency with increasing speed for all methods of computation: gross, net, work, and delta.

Effect of Work Rate on Efficiency

The data on the effect of work rate on efficiency are more inconsistent. Dickinson (27) found that efficiency remained constant with increasing workload at a value of around 21.0 percent. Inspection of her method of calculation reveals a rather interesting technique of establishing a baseline:

> Collections of expired air were made: (1) over a period of ten minutes immediately after the subject had remained at rest on the bicycle for half an hour; (2) over a period of half an hour, the first one to ten minutes of which (according to the speed of pedaling) were occupied by the exercise and (3) over a period of ten minutes immediately after the half hour period. From the second collection the total oxygen used during the period of exercise and recovery was found. The oxygen used for the exercise was taken as the difference between the total amount used during the thirty-minute period and the amount that would have been consumed during that period at the mean of the rates of oxygen consumption found for sitting on the bicycle before and after that period.

Since only "medium range" submaximal loads were used, it would seem that the energy expenditure for a given load would be slightly overestimated, thus lowering efficiency. The energy for such a work bout should have been supplied by aerobic energy sources.

The 1920 study by Campbell, Douglas and Hobson (12) revealed only slight decreases in net efficiency with increasing load. These slight differences were amplified by use of the work efficiency calculation.

Henry and DeMoor (42) used nine experienced cyclists in a study designed to investigate the effect of increasing work rate on efficiency. Two loads of 113 watts and 150 watts were employed. The mean net efficiency of 19.3 percent at 150 watts was significantly less than the 21.2 percent efficiency found at the 113 watt load. The drop in efficiency was explained as a by product of the lower metabolic efficiency of the lactic debt mechanism.

In 1952 P. O. Astrand (4) tested 21 male and 31 female adults to determine if there were efficiency differences dependent on sex. He established that for the well-trained adult individuals the net efficiency was about 23.0 percent independent of sex. He also reported the net efficiency for changing workloads. For the males the mean net efficiency at 147 watts and 196 watts was 23.3 percent and 23.7 percent respectively. The females rode absolute workloads of 98 watts and 147 watts. The mean net efficiencies for those loads were 22.5 percent and 23.1 percent. Both sets of data, male and female, reveal a fairly constant efficiency.

Data published in 1960 by I. Astrand (3) showed very low net efficiencies at very low workloads of less than 33 watts. The net efficiency values rose sharply until the workload reached about 49 watts. At higher workloads the value remained relatively stable. The net efficiency values were as low as 10.5 percent at a value of 8 watts and as high as 23.5 percent at 98 watts. Most of the data points were from a group of five female subjects.

Wasserman, Van Kessel, and Burton (59) reported very little difference in net efficiency for what they classified as moderate, heavy, and very heavy workloads. The efficiency reported was about 21 percent for steady state work.

In 1969 Whipp and Wasserman (63) presented a strong argument for the work efficiency computation. They tested eight male subjects and computed the mean work efficiency at a load of 56 watts. The investigators stated that the traditional mean work efficiency of 29.8 percent approximated the theoretical-thermodynamic efficiency of 29 percent which was computed using the same data. The strong argument advanced by these authors was that the O_2 cost of moving the legs without a load should be subtracted from the steady-state work $\dot{V}O_2$ to give an accurate measure of the efficiency of the actual muscular work. Whipp and Wasserman tested all subjects at only one workload and did not examine the effect of work rate on efficiency.

Perhaps the most complete investigation concerning the effect of work rate on efficiency was provided by Gaesser and Brooks (30). They examined efficiency as it related to changes in work rate

using the gross, net, work, and delta methods of calculation. Gross and net procedures yielded an increase in efficiency as work rate became more intense, whereas work efficiency produced a constant or slightly decreasing efficiency, and the delta computation demonstrated decreasing efficiency with increased work rate. The increasing efficiency displayed by the gross and net method of computation was said to be an artifact of calculation. Gaesser and Brooks (30) state that "a linear or slightly exponential relationship between caloric output and work rate dictates either constant or decreasing efficiency with increments in work." This result was produced by the delta efficiency definition. They further state that the difficulty involved when using the work efficiency calculation is the obtaining of 0 work equivalents. For that reason, the work efficiency calculation was difficult to apply.

It was further shown that the "theoretical-thermodynamic approach cannot be used to validate any one particular method of efficiency calculation because, irrespective of the approach, the estimation of energy expended by the subject is still obtained from $\dot{V}O_2$." The delta efficiency values ranged from 34.0 percent to 24.4 percent.

Rationale for a Decreasing Efficiency

The cause for the observed efficiency decrease could be a "shift" from slow twitch to fast twitch fibers as work increases. Costill and his group (18, 21) reported that slow twitch fibers showed greater glycogen depletion after long distance running than do fast twitch fibers. Gollnick et al. (36, 37) conducted experiments

in which both distance running for extended time periods and short sprint bouts at 150 percent of max $\dot{V}O_2$ were performed. Glycogen depletion patterns were examined and it was found that during the aerobic work bouts the slow twitch fibers exhibited greater glycogen depletion whereas during sprint work the fast twitch fibers showed a greater glycogen depletion. Both studies support the hypothesis of preferential fiber recruitment from slow twitch to fast twitch as work intensity becomes greater.

Thus far the efficiency of slow twitch as compared to fast twitch muscle has been scrutinized using isolated muscle as opposed to intact man. Davies (24, 25) showed that efficiency varied with the type of skeletal muscle. He reported that slow twitch was more efficient than fast twitch muscle, with efficiencies varying between approximately 35 and 50 percent. Wooledge (67) arrived at the same conclusions a few years later. He showed that tortoise muscle is more efficient than frog muscle in converting free energy into work as indicated by a higher ratio of work to work + heat. The work of Gibbs and Gibson and Wendt and Gibbs (32, 61) endorses the findings of Wooledge and Davies. In their studies using the muscles of the rat, a greater efficiency was found in slow twitch than fast twitch muscle. The suggestion is made that the efficiency difference is related to mechanically linked heat (representing actomyosin activity), and the heat of activation (associated with moving calcium in and out of the sarcoplasmic reticulum).

In recent studies by Costill (19, 20) distinct differences in the fiber distribution of muscle were disclosed. The mean value for percentage of slow twitch fibers was 69.4 percent for distance runners and 27.4 percent for sprinters. In a similar study the mean figure for elite distance runners was 79 percent and 57.7 percent for untrained subjects. Gollnick (35) also published data in agreement with Costill. The observations of Gollnick and Costill were confirmed by Prince et al. (53) when they stated that there was a significant trend toward more oxidative fibers in runners than weight lifters.

Whether or not the differences in fiber type between individuals involved in primarily aerobic type training and individuals whose training is primarily anaerobic exist as a product exclusively of training or as a result of heredity is yet unresolved. However, of main concern is the fact that differences exist.

Summary

Evidence has shown the inadequacy of the gross and net efficiency calculation. The work and delta efficiency definitions more closely approximate a true representation of the efficiency of the muscular work of man.

The premise of decreasing efficiency with increasing speed is widely accepted.

It is yet to be proven whether a decrease in mechanical efficiency is due to fiber type function in man. In fact, the concept of decreasing efficiency with increasing workload is yet to be totally accepted.

CHAPTER III

METHODS

Subjects

Ten subjects volunteered to participate in this study. All ten were track athletes: five distance runners and five sprinters. Neither the distance runners nor the sprinters were skilled in bicycle riding. Experimental protocol was explained to each subject and an informed consent form was signed by each subject prior to participation. (See Appendix B.)

Procedure

Maximal oxygen uptake test. A preliminary maximal oxygen uptake test was administered to each subject. The progressive maximal test was performed on a mechanically braked Monarch bicycle ergometer and used a constant pedal frequency of 60 rpm with the resistance increased by 0.5 kilopond every two minutes until the subject was unable to continue. Gas samples were collected every 30 seconds during the last two to three minutes of the test. The usual criteria of a plateau or a drop in oxygen uptake in response to an additional work level was applied in determining the maximal oxygen uptake (7). The highest value was used as the subject's maximal aerobic power.

Baseline measurement. A measurement for unloaded pedaling was taken for each subject to establish a baseline correction for the computation of work efficiency. The subjects were instructed to pedal with no load at 60 rpm. A single four minute gas collection was made after the subject had pedaled for six minutes. Unloaded pedaling measurements were duplicated on all subjects.

Submaximal work bouts. Submaximal loads were drawn at random to establish the order of testing. The absolute loads were kept below 80 percent of max $\dot{V}O_2$. The estimation was based on the max $\dot{V}O_2$ of each subject. At the beginning of all test sessions, each subject engaged in a 5 minute warm-up at approximately 30 watts. All submaximal rides were performed at 60 rpm on a mechanically braked bike. A metronome and a mark on the speedometer of the bike were used to insure proper pedaling cadence. The bicycle ergometer was calibrated prior to each testing day. Seat height was set on the first testing day by using the subject's full leg extension as a criterion. The seat height was recorded and used for each testing session thereafter. Each exercise period lasted for 10 minutes and no more than four bouts were performed in one day. On many days only two or three work bouts were performed. Two expired gas samples of two minutes duration were collected between minutes 6 and 10 of each test. During each session, a fan was directed on the subjects. Forty-eight of the fifty workloads were duplicated to insure reproducibility between days for the $\dot{V}O_2$ of a given workload.

Ventilation and gas exchange. Oxygen uptake was measured by the open circuit method utilizing meteorological balloons and a Daniel's valve. Expired gases were analyzed electronically with a Beckman E-2 O_2 analyzer and a Beckman LB1 CO_2 analyzer. These analyzers were calibrated with gas samples analyzed by the Scholander technique. To assure the accuracy of the electronic readings, two 50 ml gas samples were taken periodically from the meteorological balloons and analyzed by the Scholander technique.

Inspired minute ventilation was measured with a Parkinson-Cowan CD-4 dry gas meter and recorded with a Narco Biosystems PMP-4A recorder. The dry gas meter was calibrated against a 13.5-liter Collins Respirometer and a 120-liter Tissot gasometer with the respirometer taken as standard. Relative humidity, barometric pressure, and temperature were recorded during each test session. V_I was corrected to standard conditions (standard temperature and pressure, dry) and oxygen uptake was calculated according to standard procedures.

Blood samples and lactate analysis. Resting and exercising fingertip blood samples were taken before and during a test at the highest workload for each subject. Before the resting sample was taken, the entire hand was warmed by submersion into a plastic beaker of hot water. Three to five blood samples were then collected during the normal 10 minute exercise bout. The blood samples were collected on spot plates containing 0.05 ml of 4 percent sodium fluoride. The blood and sodium flouride were mixed

and 50 µl of the sample were placed in a tube containing 1.0 ml of 7 percent perchloric acid. The blood and perchloric acid were thoroughly mixed and placed in an ice bath for later analysis. At the completion of the exercise period all blood samples were centrifuged at 4000 rpm for 10 minutes at 0-5°C. The supernatant in the tubes containing perchloric acid and 50 µl of blood was decanted into another chilled tube and stored in a refrigerator until analysis. Each blood sample was analyzed in triplicate for lactic acid. Lactic acid was analyzed by the method of Gutmann and Wahlfeld (40). (See Appendix A for detailed description of the procedure.)

Work rate computation. Pedal frequency was recorded by use of a micro-switch attached to the ergometer frame. Each revolution of the right pedal arm tripped the switch to result in a printed record on the physiograph. The number of pedal revolutions per minute was multiplied by 6 meters to arrive at the total distance a load was moved. The product of this computation was then multiplied by the resistance setting on the bike and the product expressed as kilopond meters. Kilopond meters were converted to watts.

Conversion to kilocalories. To compute efficiency the workload and oxygen consumption were converted to kilocalories. The workloads were converted by using the relationship 427 kilopond meters per minute or 69.8 watts equals 1 kilocalorie (6). The value for the calorific equivalent per liter of oxygen was calculated by applying the formula of Zuntz and Schumberg (68) to the respiratory quotient.

The formula is expressed:

$$\text{Calories (kcal)} = 4.686 + \frac{RQ - 0.707}{0.293} \times 0.361$$

Calculation of delta values. Delta efficiency was calculated with workloads that were separated by 1.0 kilopond and 1.5 kilopond resistance settings. This means that in the calculation of delta efficiency, the data at the 0.5 kilopond resistance setting was used as a baseline for the data at the 1.5 and 2.0 kilopond settings. The data at the 1.0 kilopond setting served as a baseline for the data at the 2.0 and 2.5 kilopond settings. The data at the 1.5 kilopond setting served as a baseline for the data at the 2.5 kilopond setting. The following is an example calculation:

Given or measured information

Caloric equivalent of VO_2 at 0.5 Kp. = 4.00 Kcals/min.
Caloric equivalent of work at 0.5 Kp. = 0.50 Kcals/min.
Caloric equivalent of VO_2 at 1.5 Kp. = 7.00 Kcals/min.
Caloric equivalent of work at 1.5 Kp. = 1.30 Kcals/min.

Then:

$$\text{delta efficiency} = \frac{1.30 - 0.50}{7.00 - 4.00} \times 100 = 26.7\%$$

The absolute workload at which the delta efficiency value was plotted was determined in the following manner:

Given or measured information

Work rate at 0.5 Kp. = 29 watts
Work rate at 1.5 Kp. = 91 watts

Then:

$$\text{Absolute work rate} = \bar{X} \text{ work rate}$$

$$= \frac{29 + 91}{2} = 60 \text{ watts}$$

The relative workload at which the delta efficiency was plotted was determined by the following procedure:

Given or measured information

Caloric equivalent of VO_2 at 0.5 Kp. = 4.00 Kcals/min.
Caloric equivalent of VO_2 at 1.5 Kp. = 7.00 Kcals/min.
Caloric equivalent of max VO_2 = 21.00 Kcals/min.

Then:

$$\text{Delta relative workload} = \frac{\bar{X} \text{ caloric equivalent of } VO_2 \text{ for 0.5 and 1.5 Kp.}}{\text{caloric equivalent of max } VO_2}$$

$$= \frac{(4.00 + 7.00) \div 2}{21.00}$$

$$= 26.2\%$$

Statistics. The submaximal workloads (X variable) of the groups and the efficiencies at those workloads (Y variable) were used to compute linear regression equations by the method of least squares estimation. The difference between the regression lines for the two groups was analyzed by use of a t-test. Higher order polynomials were also fitted to the data to see if they more accurately described the relationship (66).

CHAPTER IV

RESULTS

Caloric Output and Work Rate

The relationship between caloric output and work rate is presented in Figure 1. The increase in caloric output is slightly exponential with increasing work rate. Zero work data obtained by having the subject perform no load pedaling resulted in a caloric output of 2.55 $\pm$ .13 ($\bar{X} \pm$ SE) kilocalories per minute for the distance runners and 2.81 $\pm$ .10 kilocalories per minute for the sprinters.

Baseline Considerations

The day to day variability of $\dot{V}O_2$ for no load pedaling was 12.4 percent $\pm$ 4.9 percent for the distance runners and 14.0 percent $\pm$ 7.1 percent for sprinters. The day to day reproducibility of these values was much poorer than the reproducibility of $\dot{V}O_2$ for submaximal workloads. The between day variability at submaximal workloads was 3.1 percent $\pm$ 0.4 percent for distance runners and 3.7 percent $\pm$ 0.7 percent for sprinters.

In an attempt to circumvent the inherent variability of the no load pedaling measurement, the Y intercept of a linear regression of caloric output on work rate was used to estimate a no load pedaling baseline for the work efficiency calculation. These values were 1.69 $\pm$ .13 for the distance runners and 1.98 $\pm$ .08 for the sprinters.

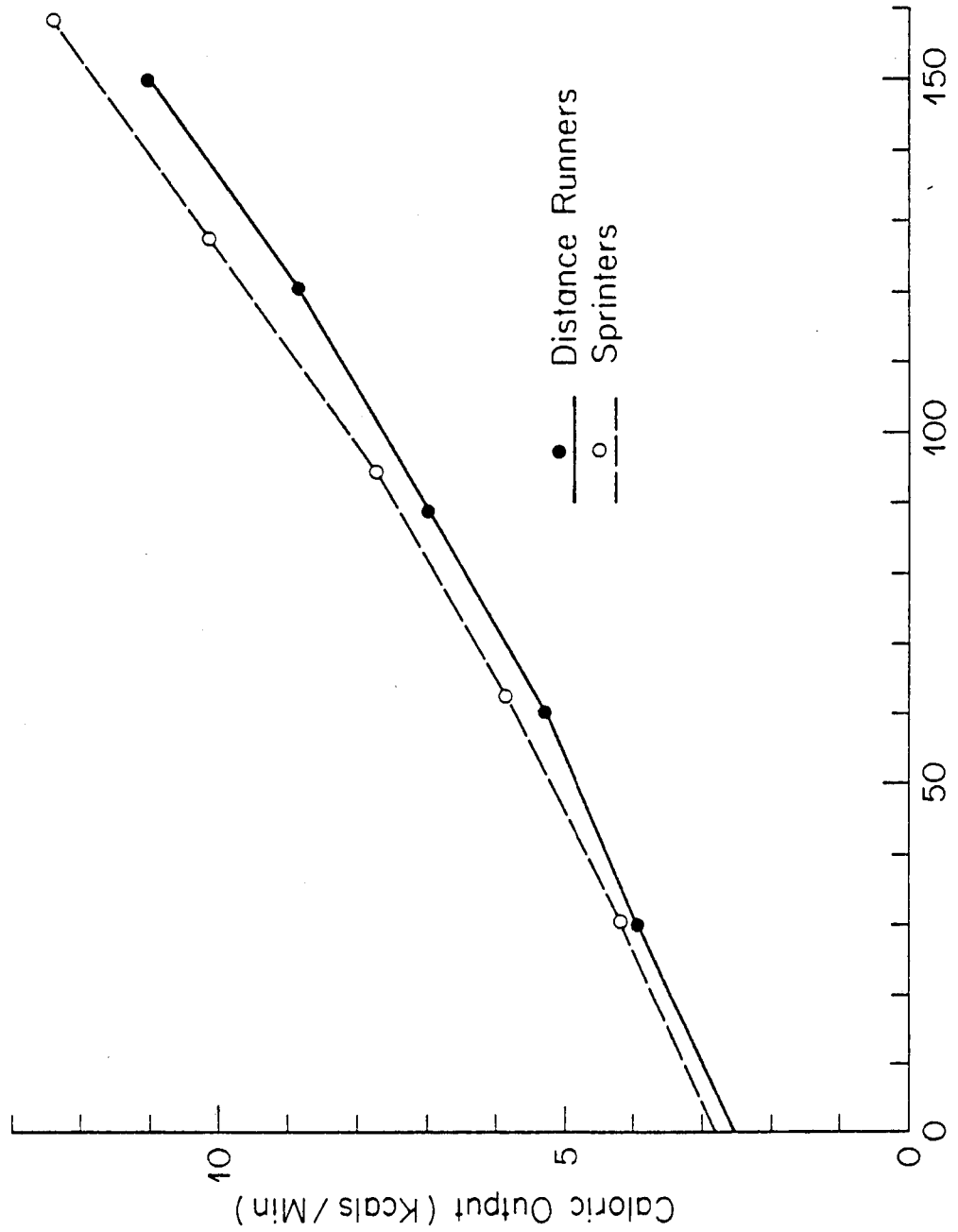

Figure 1. Relationship between caloric output and work rate. The lines represent mean values for caloric output and work rate.

Work Efficiency

Data on work efficiency for the distance runners and sprinters are listed in Tables 1 and 2 respectively. Work efficiency values for both groups decreased slightly with increasing work rate (Figure 2). A t-test showed that no significant differences ($P > .05$) existed between the means of the regression lines of the two groups at both absolute and relative workloads (Figures 2 and 3). The very low efficiencies at the work rate of 30 watts were considered to be artifacts of the work efficiency procedure, and were excluded in the determination of the regression lines in Figures 2 and 3. When the low points were included, the regression lines assumed positive slopes, indicating an increasing work efficiency. This would have been an obvious distortion of the true relationship between work efficiency and increasing work rate.

Delta Efficiency

Data on delta efficiency are listed in Tables 3 and 4. In contrast to work efficiency, delta efficiency decreased at a greater rate (as seen in the negative slopes of the regression lines in Figures 4 and 5). A t-test failed to reveal a significant difference ($P > .05$) between the means of the regression lines of the two groups at both absolute and relative workloads. The higher order polynomials were not significantly different ($P > .05$) from the linear equations so that the relationships could be explained as linear functions.

TABLE 1

VALUES FOR WORK EFFICIENCY FOR DISTANCE RUNNERS
MEASURED AT SPECIFIC WORK RATES

Subject	Absolute Workload in Watts	Relative Workload in Percent of Max $\dot{V}O_2$	Work Efficiency in Percent
1	30.0	18.0	18.1
	59.3	23.9	23.3
	89.2	30.7	25.0
	118.0	38.6	24.8
	146.1	48.3	23.5
2	29.2	20.5	18.8
	62.6	32.2	21.2
	89.2	39.3	23.5
	121.8	53.2	22.3
	157.5	68.5	21.6
3	30.6	20.0	21.8
	59.6	25.7	27.6
	88.2	38.5	22.9
	126.5	47.1	25.3
	152.0	56.9	24.1
4	30.1	17.5	17.4
	59.8	22.3	23.1
	90.8	29.4	23.5
	120.8	36.2	23.8
	148.0	46.3	21.6
5	29.2	23.1	20.5
	59.3	29.9	26.6
	88.8	38.9	26.9
	115.9	49.4	25.5
	147.4	60.4	25.1
$\bar{X} \pm$ SE	29.9 ± 0.2	19.8 ± 1.0	19.3 ± 0.8
	60.1 ± 0.6	26.8 ± 1.9	24.4 ± 1.2
	89.2 ± 0.4	35.4 ± 2.2	24.4 ± 0.7
	120.6 ± 1.8	44.9 ± 3.2	24.3 ± 0.6
	150.2 ± 2.1	56.1 ± 4.1	23.2 ± 0.7

TABLE 2

VALUES FOR WORK EFFICIENCY FOR SPRINTERS
MEASURED AT SPECIFIC WORK RATES

Subject	Absolute Workload in Watts	Relative Workload in Percent of Max $\dot{V}O_2$	Work Efficiency in Percent
6	29.8	20.7	19.3
	61.4	28.0	23.8
	91.7	37.3	23.6
	126.0	50.0	22.2
	153.6	59.1	22.0
7	30.6	25.2	19.4
	62.3	35.8	22.2
	89.3	45.4	22.9
	121.3	59.8	21.9
	159.6	76.5	21.4
8	30.5	22.2	21.5
	63.8	32.2	23.1
	96.7	42.0	23.7
	136.0	52.9	24.5
	159.0	63.2	22.9
9	30.5	23.2	21.1
	64.5	34.2	22.9
	98.0	44.9	23.6
	127.8	58.4	21.9
	152.9	66.0	22.5
10	30.9	25.4	17.8
	60.8	33.3	23.0
	95.2	46.6	22.7
	127.0	60.9	21.7
	167.3	79.4	20.9
$\bar{X} \pm SE$	30.5 ± 0.2	23.3 ± 0.9	19.8 ± 0.7
	62.6 ± 0.7	32.7 ± 1.3	23.0 ± 0.3
	94.2 ± 1.6	43.2 ± 1.7	23.3 ± 0.2
	127.6 ± 2.4	56.4 ± 2.1	22.4 ± 0.5
	158.5 ± 2.6	68.8 ± 3.9	21.9 ± 0.4

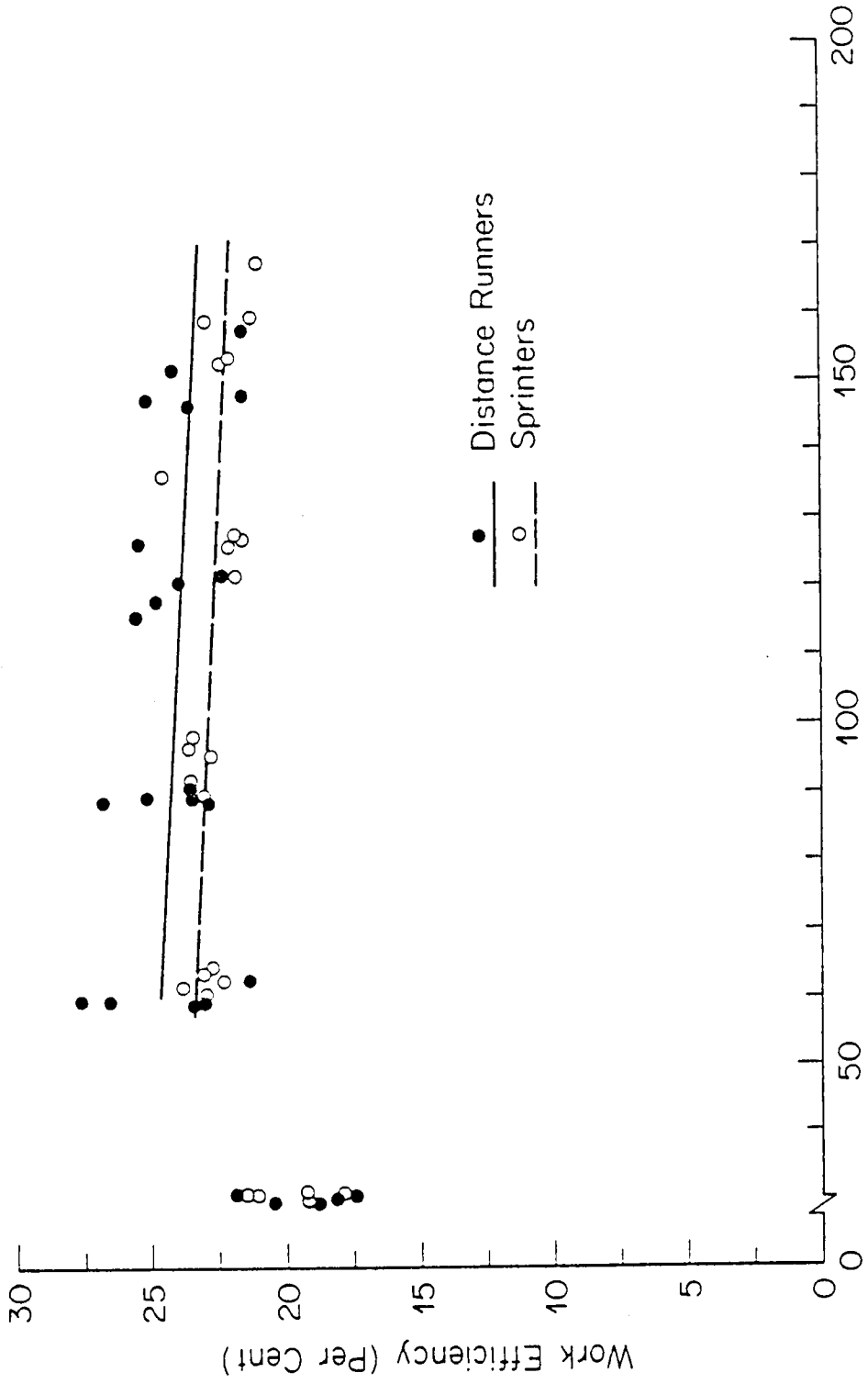

Figure 2. Relationship between work efficiency and work rate expressed in absolute terms.

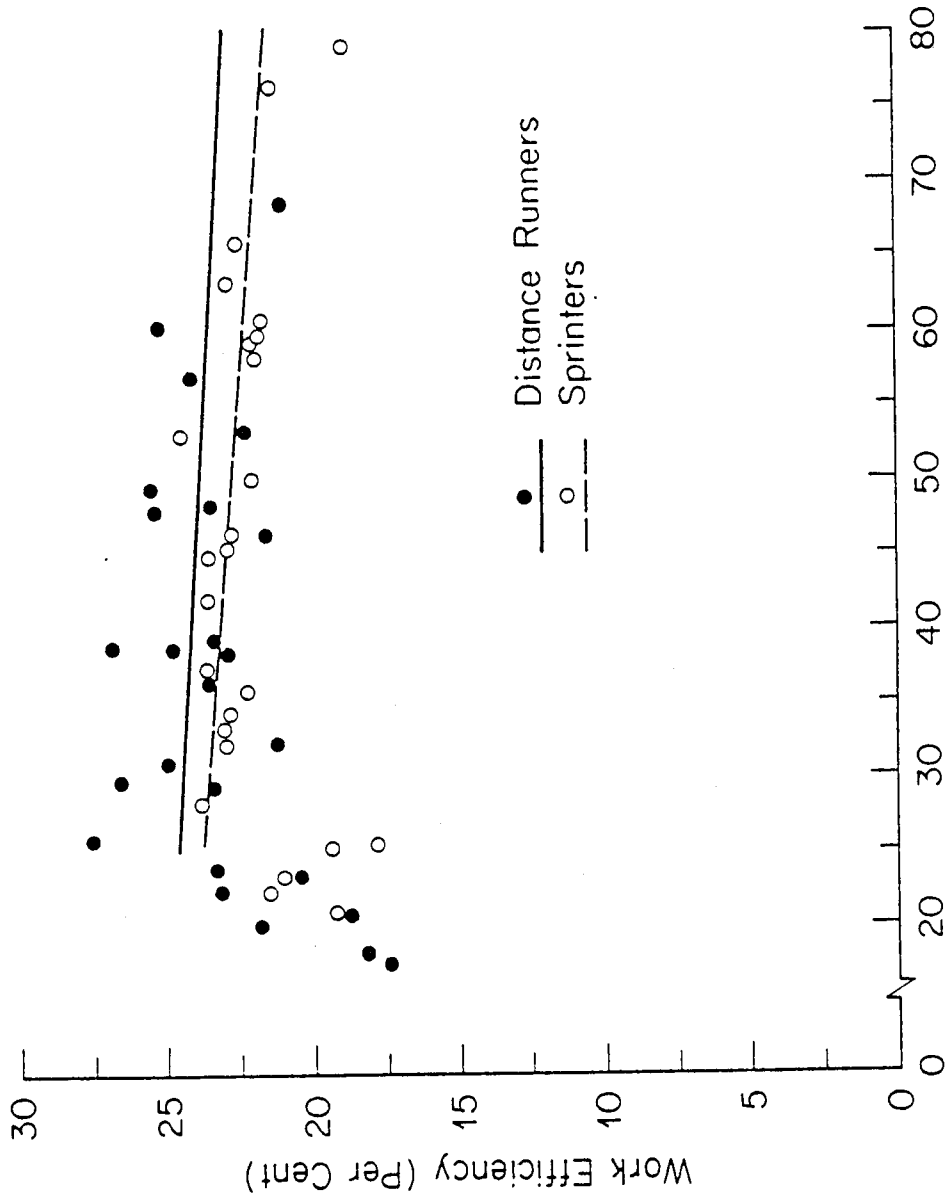

Figure 3. Relationship between work efficiency and work rate expressed in relative terms.

TABLE 3

VALUES FOR DELTA EFFICIENCY FOR DISTANCE RUNNERS MEASURED AT SPECIFIC WORK RATES

Subject	Absolute Workload in Watts	Relative Workload in Percent of Max $\dot{V}O_2$	Work Efficiency in Percent
1	59.6	24.4	30.9
	74.0	28.3	28.3
	88.4	32.2	25.9
	103.3	36.9	24.3
	118.5	41.1	22.8
2	59.2	29.9	26.7
	75.5	36.9	23.7
	92.8	43.6	23.0
	107.9	49.9	22.0
	122.9	54.6	20.6
3	59.4	29.2	23.5
	78.5	33.5	26.7
	92.0	37.4	24.2
	106.4	42.3	23.5
	120.8	46.9	24.4
4	60.4	23.4	28.5
	75.5	26.9	27.2
	89.7	30.6	23.8
	105.5	34.8	22.5
	121.5	38.2	21.9
5	59.0	31.0	31.8
	72.6	36.3	27.7
	88.0	40.7	25.5
	102.8	46.1	24.9
	117.7	50.1	23.2
$\bar{X} \pm SE$	59.5 ± 0.2	27.6 ± 1.5	28.3 ± 1.5
	75.2 ± 1.0	32.4 ± 2.0	26.7 ± 0.8
	90.2 ± 1.0	36.9 ± 2.5	24.5 ± 0.5
	105.2 ± 1.0	42.0 ± 2.8	23.4 ± 0.5
	120.3 ± 1.0	46.2 ± 3.0	22.6 ± 0.6

TABLE 4

VALUES FOR DELTA EFFICIENCY FOR SPRINTERS
MEASURED AT SPECIFIC WORK RATES

Subject	Absolute Workload in Watts	Relative Workload in Percent of Max $\dot{V}O_2$	Work Efficiency in Percent
6	60.8	29.0	26.4
	77.9	35.4	23.3
	92.7	39.5	21.8
	107.5	43.6	21.0
	122.7	48.2	20.1
7	60.0	35.3	25.4
	76.0	42.5	24.0
	93.5	49.3	21.7
	111.0	56.2	20.8
	124.5	60.9	19.7
8	63.6	32.1	24.8
	83.3	37.5	25.5
	97.4	42.6	24.6
	110.6	48.9	23.0
	127.1	52.6	22.3
9	64.2	34.0	24.9
	79.1	40.8	22.2
	93.9	45.2	22.0
	108.7	50.1	22.3
	125.4	55.4	20.8
10	63.1	36.0	26.2
	79.0	43.2	23.4
	96.5	50.0	21.2
	114.0	56.3	19.9
	131.3	62.4	18.9
$\bar{X} \pm$ SE	62.3 ± 0.8	33.3 ± 1.3	25.5 ± 0.3
	79.1 ± 1.2	39.9 ± 1.5	23.7 ± 0.5
	94.8 ± 0.9	45.3 ± 2.0	22.3 ± 0.6
	110.4 ± 1.1	51.0 ± 2.4	21.4 ± 0.6
	126.2 ± 1.5	55.9 ± 2.6	20.4 ± 0.6

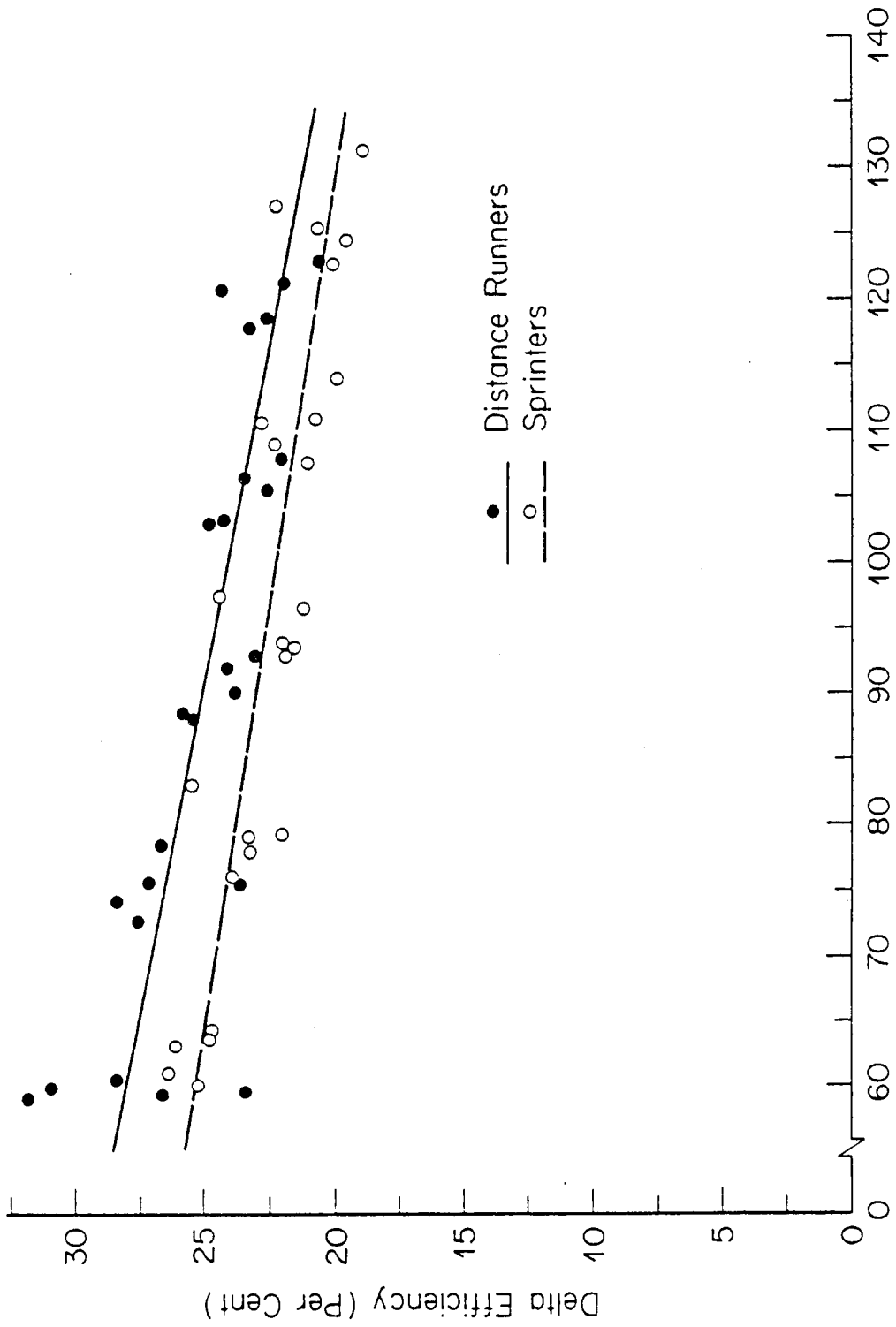

Figure 4. Relationship between delta efficiency and work rate expressed in absolute terms.

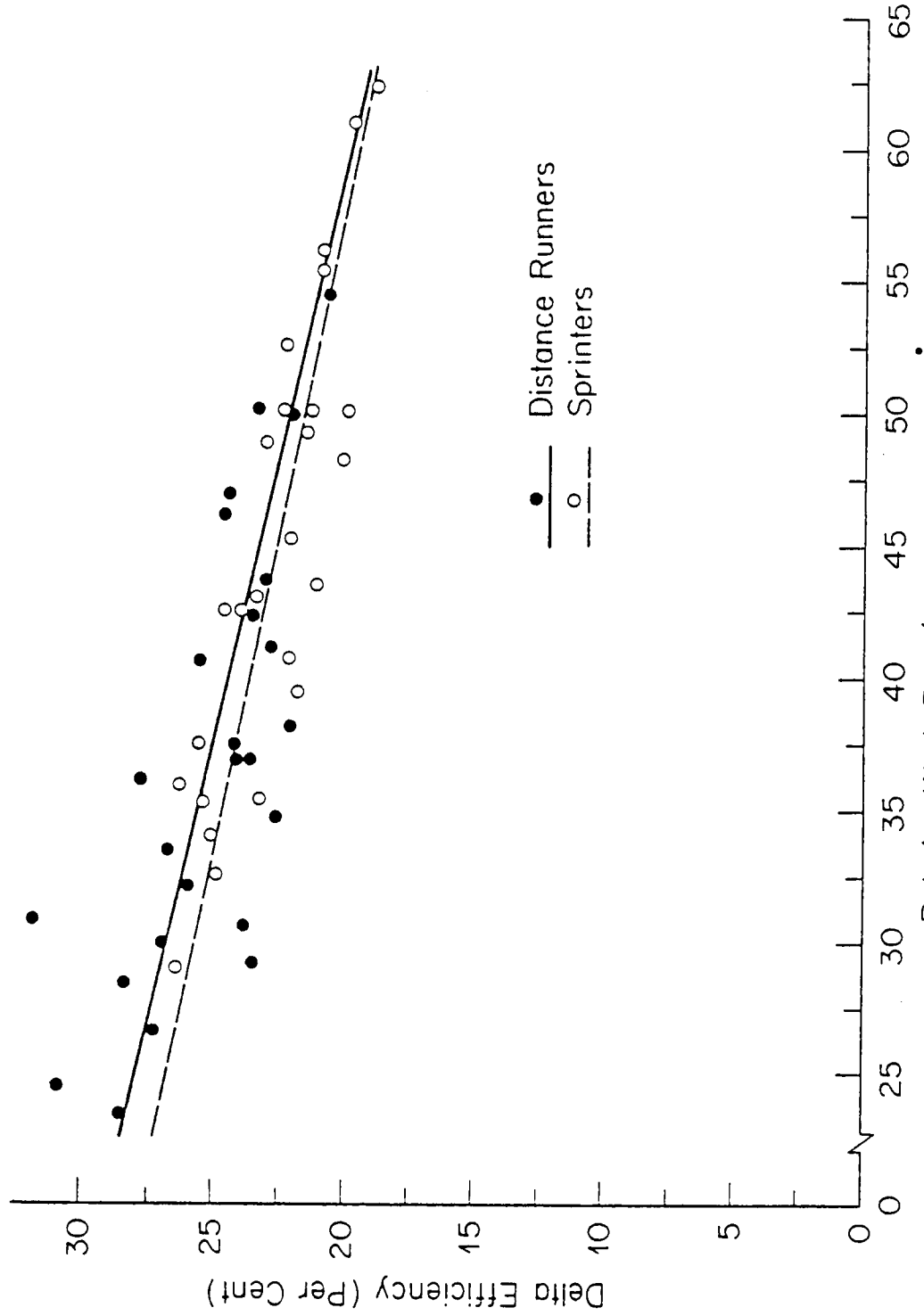

Figure 5. Relationship between delta efficiency and work rate expressed in relative terms.

Blood Lactate and R Values

Blood lactate values obtained at the highest submaximal workload for each subject are displayed in Table 5. In some cases, lactate values were obtained at a greater workload than the highest workload used in the efficiency computations. R values for the highest workloads used in the efficiency computations were $.88 \pm .02$ ($\bar{X} \pm$ SE) for distance runners and $.95 \pm .01$ for sprinters.

TABLE 5

LACTATE VALUES FOR DISTANCE RUNNERS AND SPRINTERS

Subject		Blood Lactate in Millimoles per Liter						Work Rate in Watts
Distance Runners	Time (min.)	Rest 0	2	4	6	8	10	
1		1.19	-	3.83	3.39	3.27	3.00	211.0
2		.94	-	4.00	5.66	7.41	7.33	182.4
3		.78	1.75	2.25	2.89	2.44	2.69	183.5
4		.50	-	3.66	4.38	5.16	4.88	244.6
5		.67	-	2.58	2.25	2.25	2.25	175.4
Sprinters								
6		.89	-	4.30	-	4.72	4.72	153.6
7		1.72	-	2.22	-	2.11	2.11	159.6
8		1.11	2.19	3.39	5.33	-	4.06	159.0
9		1.55	-	5.80	-	6.55	6.63	152.9
10		1.30	-	3.83	-	5.11	5.05	167.3

CHAPTER V

DISCUSSION

Work Efficiency

The exponential relationship between caloric output and work rate (Figure 1, page 23) dictates a decreasing efficiency with increasing work rate. Although the slopes of the regression lines for work efficiency are slightly negative, this method does not offer a suitable method of efficiency calculation. The difficulty involved in measuring the energy cost of moving the legs is an appertaining weakness in the work efficiency procedure. An alternative to the calculation of the calorific equivalents of the $\dot{V}O_2$ for no load pedaling is the use of the Y intercept of a regression line for each subject, i.e. caloric output is linearly regressed on work rate. However, if the relationship between caloric output and work rate is not perfectly linear (as in the present study), the use of the Y intercepts as baselines for work efficiency calculations will lead to erroneous results.

Delta Efficiency

The "floating baseline" employed in the delta efficiency calculation eliminates this problem. If the assumption can be made that each increment in caloric expenditure can be attributed to the metabolic demands of an increased work rate, then muscular efficiency is most accurately measured by the delta efficiency calaculation (30).

What, then, is the cause of the decreases in delta efficiency with increases in work rate? As previously proposed, a decreased muscular efficiency due to the recruitment of less efficient fast twitch fibers could offer an explanation. However, if that were true a difference between the regression lines of the distance runners and sprinters should exist. The data in this study failed to support the observations previously reported on isolated muscle since no significant differences were found between the two groups.

Upon inspection of the workloads one might surmise that the loads were not heavy enough to require recruitment of the inefficient fast twitch fibers. However, Milner-Brown and his collaborators (50, 51) state that recruitment takes place at low force levels. These findings are supported by Grillner and Udo (39) who state that 90 percent of the motor units in the soleus of the cat had been recruited by the time the active tension in a stretch reflex had reached 50 percent of its final value. Since the sprinters possess a preponderance of fast twitch fibers, it is reasonable to assume that the "switch" to those fibers had occurred at the loads utilized in the current experiments.

A second question may then be raised. Is the decrease in efficiency observed in the present study due to a decrease in the efficiency of the muscle used for accomplishing the measured work? Fales, Heisey, and Zierler (29), used <u>in situ</u>, intact muscle of the dog and reported an increasing efficiency with increasing load. It is possible that these results cannot be extrapolated to exercising

intact man, but it does raise a doubt about the concept of decreasing muscle efficiency with increasing work rates.

The actual accounting for the decreasing delta efficiency may be found in unmeasured work. As the workload becomes more intense the action of fixator muscles of the pelvis, back, and forearms may increase significantly. This unmeasured work may increase in greater proportion than the metabolism of the pedaling muscles and cause a decrease in the efficiency calculated for the external work done. If such is the case, it is the total body efficiency that is decreased and not that of the muscles performing the work. However, it cannot be ruled out that a decreasing total body efficiency, and a decreasing efficiency of the muscles doing the actual work may be in effect simultaneously to produce the results reported in these experiments.

The delta efficiency values reported in the present study were lower (about 3 percent to 4 percent in terms of efficiency) than those reported by Gaesser and Brooks (30) at comparable workloads. However, this difference may be accounted for somewhat by the difference in the bikes that were used to measure the work. In his comment of the Monarch bicycle ergometer, P. Astrand (5) states that "friction in the transmission, mainly in the chain, increases the workload by about 9 percent above the one calculated from braking force and distance moved." Since Gaesser and Brooks (30) used an electrically braked bike, this friction component did not act on the work rate in their investigation. A 9 percent adjustment in the work rates recorded in this study would tend to align the efficiency values of the two sets of experiments.

Anaerobic Energy Considerations

The lactate values were measured at the highest work rate performed by the subject. In each case the measurements had leveled off or were decreasing by the latter stages of exercise. Such a response indicates that the energy demands are being met primarily by aerobic means. However it may still be argued that in the earlier phases of exercise (minutes 4-8) anaerobic mechanisms are supplying ATP. This would result in an overestimation of mechanical efficiency based on $\dot{V}O_2$ alone. The contribution of anaerobic glycolysis may be calculated from lactate production (10).

To do this calculation, values for subject 10 from minutes 4-8 were chosen because this was the greatest rate of change of blood lactic acid measured in this study. The calculations should represent the upper limit of measurement error.

The lactic acid concentration at minute 4 in the exercise test was 3.83 millimoles per liter and had shown a rise to 5.11 millimoles per liter by minute 8. Assuming equal incremental changes per minute, lactic acid production would be .32 millimoles lactic acid per liter per minute. The body weight of the subject was 77 kilograms, approximately 60 percent of which was water. Assuming an equal distribution of lactic acid throughout the body water, then 46 liters times .32 millimoles lactic acid per liter per minute equals a production of 14.7 millimoles lactic acid per minute. This can be multiplied by 1.5 millimoles of ATP per millimole lactic acid (assuming glycogen as a substrate) to yield 22.05 millimoles of ATP per minute via anaerobic glycolysis.

The steady state level $\dot{V}O_2$ at this point was 2.62 liters per minute which yields 117 millimoles O_2 used per minute. At a P/O ratio of three, 702 millimoles of ATP are produced aerobically. The 22 millimoles of ATP via anaerobic glycolysis would amount to about 3 percent of the total rate of ATP production. These calculations suggest that a slight underestimation of the energy (ATP) requirement, and consequently an overestimation of efficiency, might result in the early phases of exercise. It must be pointed out that changes in blood lactic acid values were minimal (minutes 6-8) or nonexistant (minutes 8-10) during the periods in which $\dot{V}O_2$ was measured.

CHAPTER VI

SUMMARY AND CONCLUSIONS

On the basis of the literature it was concluded that there were differences between distance runners and sprinters in terms of muscle fiber type. That is, distance runners possessed predominantly slow twitch muscle fibers whereas sprinters possessed fast twitch fibers. Through studies on isolated muscle, the fast twitch fibers were shown to be less efficient than slow twitch fibers. Recruitment of the less efficient fast twitch fibers with increases in work intensity was also shown to occur. It was believed that efficiency differences existed between distance runners and sprinters which could be explained on the basis of muscle fiber type.

The purpose of this study was to investigate changes in muscular efficiency (delta and work efficiency) in highly trained distance runners and sprinters as the intensity of work increases. Five distance runners and five sprinters volunteered to participate in the study.

The formulae for calculating delta efficiency and work efficiency were stated:

$$\text{delta efficiency} = \frac{\text{Caloric equivalent of delta work accomplished} \times 100}{\text{Caloric equivalent of delta energy expended}}$$

$$\text{work efficiency} = \frac{\text{Caloric equivalent of physical work performed} \times 100}{\text{Caloric equivalent of } O_2 \text{ used during work} - \text{Caloric equivalent of } O_2 \text{ used during unloaded pedaling}}$$

Each subject rode a series of five randomized, absolute workloads on a Monarch bicycle ergometer. The workloads were ten minutes in duration. Two expired gas samples of two minutes duration were collected between minutes 6 and 10 of each test. $\dot{V}O_2$ was computed and used to calculate work and delta efficiency. Efficiency (delta and work) values were regressed on work rate (absolute and relative) for each group. The means of the regression lines for the distance runners and sprinters were evaluated for significant differences with a t-test. The mean caloric outputs at their respective mean work rates were plotted for each group.

The $\dot{V}O_2$ of unloaded pedaling was determined and due to poor day to day reproducibility, (12.4 percent $\pm$ 4.9 percent for the distance runners and 14.0 $\pm$ 7.1 percent for sprinters) was deemed unacceptable as a baseline correction factor for the work efficiency calculation. For each subject a linear regression of caloric output on work rate was calculated. The Y intercept was used as a basis for computing work efficiency.

Because of the complexity of establishing a baseline, it was concluded that work efficiency was not a practical method of efficiency calculation.

Caloric output proved to be slightly exponential with increasing work rate. Delta efficiency best represented the exponential relationship between caloric output and work rate. For distance runners and sprinters delta efficiency decreased with increasing work rate.

There was no significant difference ($P > .05$) between distance runners and sprinters in terms of work or delta efficiency. This was true at absolute and relative workloads.

The decreases in efficiency could not be ascribed to the recruitment of less efficient fast twitch fibers since no significant differences existed between the two groups.

It was proposed that unmeasured work done by the fixator muscles of the pelvis, back, and forearms might be a reason for the decreasing mechanical efficiency observed with increasing work rate.

CHAPTER VII

RECOMMENDATIONS FOR FURTHER STUDY

Further investigation into the changes in efficiency with increasing work rate is advised. Refinements of this study could be accomplished in several ways. Electromyography techniques could be employed to measure the contributions of the fixator muscle groups. The same protocol could be applied to work done on a treadmill. In this manner it might be possible to eliminate a great deal of the muscle activity which is extraneous to measured work. Muscle biopsies might also be performed to determine the fiber type of each subject.

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LIST OF REFERENCES

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APPENDIXES

APPENDIX A

ENZYMATIC LACTIC ACID ANALYSIS

LACTIC ACID PROCEDURE FOR TURNER 450 FLUOROMETER

$$\text{(L+) Lactic acid} + \text{NAD} \underset{\longleftarrow}{\xrightarrow{\text{LDH}}} \text{Pyruvic acid} + \text{NADH}$$

In the presence of LDH, lactic acid and NAD are converted to pyruvic acid and NADH respectively. As this reaction will not go to completion unless the pyruvic acid is removed from the mixture, a hydrazine-glycine buffer is added in order that the hydrozine will complex with the pyruvic acid.

Reagents

1. 70 percent Perchloric Acid ($HClO_4$)
2. Hydrazine-Glycine Buffer
   Hydrazine Sulfate-Sigma No. H-3376
   Glycine -Sigma No. G-7126
3. Lactic Dehydrogenase (LDH)-Sigma No. L-2625
4. Nicotinamide Adenine Dinucleotide, Reduced Form
   Sigma No. N-8129
5. Lithium Lactate Standard Stock
   Dry 535-540 mg of Lithium Lactate at 80°C overnight.
   Add 532.5 mg of the Lithium Lactate to 400 ml of water.
   Add 0.25 ml of concentrated H_2SO_4. Make up to 500 ml in a volumetric flask. 1.0 ml = 1000 µg LA
6. 4 percent NaF

Daily Working Solutions

1. Deproteinizing Agent - 7 percent Perchloric Acid (1.00 ml/assay). Add 6.0 ml of 70 percent $HClO_4$ to a flask and add water up to 100 ml. (Refrigerate)

ml 7% $HClO_4$	100	200	300	400	500	1000
$HClO_4$	6	12	18	24	30	60
H_2O	94	188	282	376	470	940

2. Hydrazine Glycine Buffer (2 ml/assay)
   a. 0.4 Molar Hydrazine and 0.5 Molar Glycine. Add 3.76 gm Glycine and 5.20 gm Hydrazine Sulfate to about 80 ml of water.
   b. Adjust pH to 9.0 with concentrated NaOH and bring up to 100 ml with water.

Assays	24	37	50	75	100	250	500
ml Buffer	50	75	100	150	200	500	1000
gm Hydrazine Sulfate	2.60	3.90	5.20	7.80	10.40	26.00	52.00
gm Glycine	1.88	2.82	3.76	5.64	7.52	18.80	37.60
ml H_2O	35.00	60.00	80.00	120.00	170.00	400.00	800.00
Final volume	50.00	75.00	100.00	150.00	200.00	500.00	1000.00

3. Lactic Dehydrogenase
   To a given volume of buffer add enough LDH so that the final concentration is 10 U LDH/ml buffer.

Assays	25	37	50	75	100
ml Buffer	50	75	100	150	200
ml LDH (5900 U/ml LDH)	0.085	0.127	0.169	0.254	0.339

4. β-Nicotinamide Adenine Dinucleotide, Reduced Form
   Add enough NAD to a given volume of buffer so that the final concentration is 1 mg NAD/ml buffer.

Assays	25	37	50	75	100
ml Buffer	50	75	100	150	200
mg NAD	50.0	75.0	100.0	150.0	200.0

5. Working Standards
   Add water-H_2SO_4 solution to all volumes of stock to make up correct standards (0.25 ml concentrated H_2SO_4 made up to 500 ml).

   a. Add 2.5 ml of stock and make up to 100 ml = 25 µg/ml
   b. Add 5.0 ml of stock and make up to 100 ml = 50 µg/ml
   c. Add 10.0 ml of stock and make up to 100 ml = 100 µg/ml
   d. Add 15.0 ml of stock and make up to 100 ml = 150 µg/ml
   e. Add 20.0 ml of stock and make up to 100 ml = 200 µg/ml

Sample Collection

1. 0.05 ml of 4 percent NaF is added to spot plate and dried at 80°C overnight.
2. Put blood sample on spot plate containing the 4 percent NaF. Mix.
3. Using 50 µl micropipettes, transfer 50 µl of the sample to a cold test tube containing 1.0 ml of 7 percent $HClO_4$. Mix and either put on ice or refrigerate.
4. Centrifuge at 4000 RPM for 5 minutes at 0-5°C.
5. Decant supernatant into another chilled tube.
6. Refrigerate or put on ice until analysis.

Analytical Procedure

Standards and unknowns should be analyzed in triplicate.
Add 0.1 ml of Blank, Standards, and Samples to fluorometer tubes:

a.	Blank	0.1 ml of 70 percent $HClO_4$
b.	Standard 1	0.1 ml of Standard 1
c.	Standard 2	0.1 ml of Standard 2
d.	Standard 3	0.1 ml of Standard 3
e.	Standard 4	0.1 ml of Standard 4
f.	Sample	0.1 ml of Sample

Treat all of the above tubes as follows:

a. Add 2.0 ml of buffer enzyme solution to each tube.
b. Mix thoroughly.
c. Incubate in water at 30°C for 30 minutes and cool to room temperature.

Fluorescence Determination

Read fluorescence at 360/460 with 15 nm slits.
Use the blank to correct for all readings.

Calculations*

1. Subtract the blank for each standard and sample.
2. Use formula, make a curve or fit a line of least squares to fluorometer values to determine unknown.

Formula:

$$\text{mg/100 ml blood} = \text{sample} \times \frac{1.05}{0.1} \times \frac{1}{0.05} \times \frac{100}{1000} \text{ m moles/l or}$$

$$\text{mEq} = \frac{\text{mg/100 ml}}{9.008}$$

*Due to quenching by the fluorometer, the Standard Curve is curvilinear, not linear. In order to correctly calculate concentrations, a higher order polynomial or a graph of the Standard Curve must be used.

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APPENDIX B

INFORMED CONSENT FORM

Informed consent for participation in the study to measure the changes in muscular efficiency in trained and untrained subjects as the intensity of work increases.

I, _____, hereby volunteer to participate in a research study designed to measure the changes in muscular efficiency in trained and untrained subjects. I am aware that I will exercise on several occasions on a bicycle ergometer. On one occasion I will take a physical work capacity test and on other occasions I will exercise at loads below maximum. In these latter tests I understand that the duration of the test is 10 minutes and that 4 minutes after the test my finger will be pricked with a sterile lancet to obtain a few drops of blood.

While there are risks associated with the exercise tests (including the possibility of a heart attack), I realize that this risk is minimal for someone who is fit enough to participate in competitive running competition and has a normal resting ECG.

All my questions regarding these experiments have been answered to my satisfaction. I will be allowed to withdraw from this research study at any time.

Signature: _____

Date: _____

Witness: _____

VITA

Michael Kelly Stuart was born in Meridian, Mississippi, on January 23, 1947. He attended elementary school in Hattiesburg, Mississippi. In 1959 he moved to Starkville, Mississippi and was graduated from Starkville High School in June, 1965. He entered Mississippi State University in September of the same year and graduated with a Bachelor of Science degree in accounting in August, 1969.

In January, 1970 he accepted a job with Holiday Inns, Inc. in Memphis, Tennessee as a corporate accountant. He left Holiday Inns in 1971, and gained employment as a sales representative for Office Supply Company of Columbus, Mississippi.

In September, 1972 he accepted a graduate assistantship at Mississippi State University and began study toward a Master's degree in physical education. This degree was awarded in August, 1974.

He then entered the Graduate School at the University of Tennessee, Knoxville in September, 1974. He completed the requirements for the Doctor of Education degree with a major in physical education in December, 1977.

The author is a member of the Southeast American College of Sports Medicine, American College of Sports Medicine, and the American Alliance for Health, Physical Education, and Recreation.

He is married to the former Suzanne McIlwain of Starkville, Mississippi.