PHYSIOLOGICAL CHANGES DURING PROLONGED WORK ON A BICYCLE ERGOMETER

---

by

Retief Kok

DECLARATION

I hereby declare that this thesis, presented to the Faculty of Science, Potchefstroom University for Christian Higher Education, for the degree Magister Scientium, is my own work and has not been submitted for any other degree at any other University.

_____ _____

DATE R. KOK.

A Thesis

Presented to

the Department of Physiology,

Potchefstroom University

for

Christian Higher Education

In partial fulfillment of the

Requirements for the Degree

Master of Science

December 1970

ACKNOWLEDGEMENTS

I would like to express my sincerest appreciation to the Chamber of Mines of South Africa for the opportunity granted to me to utilize for my thesis the data obtained during an official Laboratory research project.

I am deeply indebted to Professor C.H. Wyndham and Professor N.B. Strydom of the Human Sciences Laboratory, under whose guidance this study was carried out.
Dr. C.G. Williams, now of Stellenbosch University, provided me with criticism and advice during the collection of the data.

To the late Professor P.J. Hamersma, who was my promotor during the early stages of the study, my heartiest thanks for encouragement to indulge in future study.

Dr. J.J. van der Walt, my promotor during the final stage of the study and Professor P.J. Pretorius of the Potchefstroom University for Christian Higher Education are cordially thanked for their interest and assistance in the preparation of this thesis.

A special word of thanks to the entire staff of the Human Sciences Laboratory for technical assistance given in carrying out the study which forms the basis of my thesis. In this regard I would especially like to mention the names of Messrs. A.J.N. du Raan, B. Liversage and Mrs. M. von Rahden. Our librarian, Mrs. A. Margo, assisted materially in obtaining references on the subject.

Mr. D. Rabe is thanked for the careful editing and drawing of the figures.

Furthermore, I would like to extend my thanks to the four persons who acted as subjects for the study; without their co-operation the study would not have been possible.

To my parents, my sincere appreciation for their extensive interest and encouragement during the study.

The task of typing was skillfully performed by my wife, Marthie. I thank her for her moral assistance, patience and sacrifice while I was engaged on research for this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

The human body is occasionally expected to perform work under different types of stress. In the Gold Mining Industry, for instance, work conditions can vary considerably in as far as environmental temperature, humidity, wind velocity, radiation, illumination, noise and other external factors are concerned. Apart from these demanding stress conditions the rate of work expected from a man is also important. As most work performed underground is of a continuous nature, it was considered essential to investigate whether an "optimum" level of energy expenditure could be established at which men can be expected to work for prolonged periods. Different types of work demand different levels of energy expenditure. If the work load to be performed by the individual is too high, it might endanger his health or lead to fatigue.

The rate of work which an individual can perform for prolonged periods daily, month after month, has given rise to considerable controversy. Various criteria have been proposed in the past to predict an individual's capacity for prolonged work.

Christensen (35) employed a somewhat empirical basis for the "safe" limit. He found that lumberjacks, on high financial incentives, normally worked at levels of about 50 per cent of their aerobic capacities for prolonged periods. The Max Planck Institüt für Arbeitsphysiologie (91)

supports the idea that an individual can work safely at a level of work which produces a heart rate of about 120 beats per minute. According to their findings this heart rate corresponds to a level of 30 per cent of the individual's maximum oxygen intake value.

Wyndham et al. (121) suggested that a level of 55 per cent of the maximum oxygen intake is the optimum level of energy expenditure. This assumption is made on the basis of the onset of anaerobic metabolism, as indicated by an increase in "excess lactate", a parameter introduced by Huckabee (73).

An answer to this problem will be of great value to industry with respect to the selection of labourers for tasks of different intensities. During a normal eight-hour shift due allowance should be made for a man's capacity to keep pace at a certain level of energy expenditure without developing fatigue. Neglect of such an allowance will not only result in a reduction of productivity, but it can, moreover, endanger the health of the individual.

(a) STATEMENT OF THE PROBLEM

This study was performed in order to test the validity of various criteria proposed in the past with regard to the optimum rate of work that can be expected of a man if he is to perform work continuously for prolonged periods. The literature indicates that observations obtained during relatively short work periods were in most cases extrapolated to apply to prolonged work.

In fact, very few of the authors verified their hypotheses in studies where work was performed continuously for the duration of a full shift.

It remains an open question whether results obtained during short-term exercise can be validly used to predict an individual's capacity for prolonged work.

(b) LIMITATION OF STUDY

A major limitation of this study was that a small number of subjects was examined. The number of subjects was limited to four, due to the scope of the experiment. Not only was work performed for up to eight hours per day, but at least three repeat experiments were done at each work load. This contributed to an increased reliability of the observations obtained on each individual. Furthermore, a large number of blood samples was taken daily; with more subjects the number of blood samples would have been too many to analyse on a daily basis.

The subject's outside activities, especially during week-ends, could not be controlled. The subjects were, furthermore, studied in the post-prandial state of nutrition which might have led to small errors.

Arterialized blood was obtained from a preheated fingertip for the determinations of lactate, pyruvate and glucose concentrations. These values might be different to those obtained from arterial blood, but

due to the large number of observations which had to be made on each individual, arterial punctures were considered impractical.

The data described are those for highly trained individuals and therefore the values obtained might be an overestimation of what could be expected from mean population values.

Another important factor is that the subjects worked for prolonged periods without ingestion of food. Water was, however, supplied ad libitum during the work period.

The work was performed continuously. This is not normal in the industrial situation, as rest periods occur during the performance of almost all types of work.

(c) SIGNIFICANCE OF THE STUDY

This study proposes to indicate the optimum level of work which can be performed daily for prolonged periods by highly trained men. It also illustrates the changes in physiological parameters during the performance of work. The different factors which limit a man's capacity for prolonged work are evaluated.

CHAPTER 2

LITERATURE REVIEW

The first significant studies on exercise physiology were carried out by Hill and associates (66). Following the observation made by Fletcher and Hopkins (55) that muscle fibers require oxygen in order to contract, they mainly examined the role of oxygen supply and utilization during exercise.

Extensive research has since been done by different physiologists; however, it concentrated mainly on changes in different parameters during short-term exercise and recovery. The effects of prolonged exercise on the human being, however, have not been studied extensively.

1. OXYGEN CONSUMPTION

Hill and Lupton (66), and Bang (20) found that oxygen intake during moderate exercise reaches a "steady state" about 2½ minutes after the commencement of exercise. They postulated that this "steady state" represents the state when the rate of lactic acid production is balanced by the rate of its oxidative removal in the working muscles, and that the level of the "steady state" in oxygen consumption depends on the severity of the exercise. Åstrand (14), however, showed that a "steady state" in oxygen consumption is absent during light and moderate work. No "steady state" is reached during severe exercise, as the available oxygen taken up by the lungs and carried by the blood does

not meet the oxygen requirements of the working muscles. Hill et al. (66) showed that an oxygen debt is formed under conditions of strenuous exercise; this debt being re-paid during the recovery period. From the results of experiments on heat production in muscle, they concluded that energy is yielded under anaerobic conditions and that recovery is an aerobic process in muscles.

Lukin and Ralston (84) found that a relative "steady state" exists during light and moderate work. The oxygen intake showed fluctuations of as much as 35 per cent on a minute to minute basis. They ascribed the fluctuations in oxygen intake to changes in the number of muscles which are active during the exercise period. A steady increase in oxygen intake was, however, noted during heavy exercise which could be endured for about 35 minutes.

Grimby (61), and Åstrand and Saltin (17), among others, indicated that a steady state in oxygen intake does not occur during submaximal work.

Several investigators have indicated that a functional relationship exists between oxygen intake and work rate, which can be expressed as a two-component curve (Åstrand (14), Taylor et al. (111), Wyndham and others (119)). The first component is a linear relationship between values of oxygen intake and submaximal work rates; the second component is the horizontal part of the curve when oxygen intake values remain constant notwithstanding increases in work load.

2. MAXIMUM OXYGEN INTAKE

The oxygen intake of an individual reaches a maximum value with an increase in work load. This value is known as the individual's maximum oxygen intake. Hill (66), Bang (20), and Åstrand (14), among others, observed that differences exist between individuals with regard to their maximum oxygen intake values.

Hill and Lupton (66) ascribed the maximum oxygen intake limit in healthy individuals to inadequate oxygenation of blood in the lungs and/or a limited blood outflow from the heart.

Hill, Long and Lupton (64) found that different types of body exercise lead to different maximum oxygen intake values for the same individual. This phenomenon was explained by Åstrand (18) to be due to the number of muscles involved in the exercise activity. Figures obtained by Christensen and Högberg (38) on the maximum oxygen intake values of a group of subjects were consistently higher during skiing than those obtained on a treadmill or bicycle ergometer. This point was illustrated by Duner (49) in his study on maximum oxygen intake while work was being performed with one or both legs on a bicycle ergometer. A comparison by Asmussen and Hemmingson (8) between arm and leg work indicated the same trends.

Experimental techniques for measuring maximum oxygen intake were developed by Åstrand (14) and Taylor *et al.* (111). Various criteria were employed in order to decide whether an individual did in fact reach his maximum oxygen intake value. Taylor *et al.* (111), who determined the oxygen in-

takes of individuals while they ran on a treadmill at 7 miles per hour, assumed that the maximum was reached when an increase of 2½ per cent in the grade of the treadmill altered the increase in oxygen intake by less than 0.15 litres per minute. This was based on the finding that a 2½ per cent increase in grade caused a mean increase of 0.299 ± .087 litre per minute in oxygen consumption at sub-maximal work loads. The maximum oxygen intake value was thus taken as the point where the oxygen intake/work load relationship departed from linearity. Åstrand (14) used the point where it is obvious that the curve flattens off, or, in cases where flattening of the curve was not observed, where individuals had blood lactic acid concentrations in excess of 70 mg %.

The above criteria were criticized by Wyndham and co-workers (119) on the grounds that maximum values were not necessarily obtained under such conditions. They concluded that the most reliable method for the determination of maximum oxygen intake is by measuring oxygen intake at various work loads. A curve should be fitted to the values obtained and tested for goodness of fit. A comparison of the three mentioned techniques made by Wyndham and others (119), indicated that the criteria as proposed by Åstrand (14), and Taylor et al. (111) did in fact underestimate an individual's maximum capacity.

All the above-mentioned techniques, however, require that individuals being tested should work at relatively strenuous loads, in order to reach their maximum oxygen intake values. Tests for maximum oxygen intake are

furthermore, not advisable for all people, especially in the case of older individuals or people with cardiorespiratory diseases, as it might lead to overexertion during the test. Moreover, a high degree of co-operation and motivation is required of subjects to ensure that maximum values are in fact achieved.

Indirect techniques, based on the oxygen intake/heart rate relationship, were therefore introduced. Åstrand and Rhyming (16), Margaria (85), and Irma Åstrand (10) proposed nomograms for the estimation of maximum oxygen intake from measurement of heart rate alone, or from both heart rate and oxygen intake at submaximal levels of work.

Binkhorst and van Leeuwen (25) proposed a method based on direct measurements of oxygen uptake on a bicycle ergometer during a continuously increasing work load. Maximal effort and motivation of subjects are, however, neccesary if the above-mentioned test is to be performed. Åstrand and Saltin (17) proposed a similar type of test in which the subject is able to endure the work load for about two to eight minutes. Blood lactate values of 100 mg % were regarded as an indication that the maximum oxygen intake value had been reached. Maritz et al. (88) criticised the criteria used by the mentioned authors to decide whether or not the peak value had been reached. They proposed that heart rate and oxygen intake should be determined at, at least, three submaximal work loads. These two parameters should then be plotted against each other and an extrapolation of the curve to a heart rate value of 180 beats per minute will then give an estimation of the maximum oxygen intake of the individual.

It was pointed out that this maximum heart rate value is applicable to healthy, young males at a medium altitude of 4,750 feet above sea level.

Issekutz and others (77) used the respiratory quotient during work to predict maximum oxygen intake. A RQ value of 1.15 was taken as the level at which an individual had reached his maximum capacity. They stated that this method is independent of sex and age and gives a good approximation, generally better then 10 per cent, of the maximum oxygen uptake.

An individual's maximum oxygen intake value remains relatively constant over long periods. Irma Åstrand and co-workers (12) showed that no change in maximum capacity occurred over a four-year period in a group of subjects who remained in a good state of physical fitness. Taylor et al. (111) indicated the same trend in a group of students over a period of 14 months.

The maximum oxygen intake of an individual, however, can decrease under certain circumstances. Taylor et al. (112) demonstrated that prolonged bedrest led to a decrease in aerobic work capacity. Respiratory and cardiovascular diseases markedly decrease an individual's maximum oxygen intake. Irma Åstrand (10), in a study on workers of different age groups, showed that there was a general decrease in physical work capacity with an increase in age above 20 years.

An increase in maximum oxygen intake of subjects during a training regime of approximately sixteen weeks was reported by Williams and colleagues (117). The

average increase was found to be 7 per cent, whereas Robinson and Harmon (104) reported increases of as much as 17 to 18 per cent. The percentage increase in maximum oxygen intake due to training, as described by Knehr et al. (80) is in agreement with the finding of Williams and colleagues (117).

3. EXERCISE AND METABOLISM

The maintenance of cell functions, life and the performance of work by living matter is dependent upon the continuous supply of adequate amounts of oxygen to the tissues. Under aerobic conditions adequate amounts of oxygen are supplied to the tissues by means of respiration. Energy is liberated under such circumstances by an in-vivo oxidation of various organic substances to water and carbon dioxide. There is, however, another energy-yielding mechanism, known as glycolysis, which comes into operation under stress conditions. A glucose molecule can be split into two molecules of lactic acid in the complete absence of oxygen. Energy is released during this process. This type of energy release is known as anaerobic metabolism. Anaerobic metabolism occurs during the performance of almost all heavy tasks.

4. ANAEROBIC METABOLISM

This involves the supply of oxygen in the absence or partial absence of respiratory oxygen.

(i) Oxygen debt

The classical studies of Krogh and Lindhard (82), and Hill and coleagues (66) indicated that there is a direct relationship between lactic acid production and the oxygen debt incurred during exercise. Subsequently, different authors showed that the relationship between a contracted oxygen debt and lactic acid is a complex relationship. Owles (95) showed that an oxygen debt can occur during exercise with no increase in lactic acid above resting values. This finding was confirmed by Margaria et al. (87), who found that oxygen debts of up to 4 litres can exist without any increase in blood lactic acid. Studies by Asmussen (6), Christensen and Högberg (38), and Lukin and Ralston (84) showed that the oxygen debt incurred during exercise is not equal to the oxygen deficit.

(ii) Lactic acid

Experiments done by Fletcher and Hopkins (55) showed that an isolated muscle preparation can contract in the complete absence of oxygen and that lactic acid was formed in the muscle under such circumstances. If oxygen was then administered the amount of lactic acid in the muscle decreased. They postulated that the occurrence of lactic acid in stimulated muscle is related to the availability of oxygen.

Hill and Lupton (66), Hill et al. (65) and Jervell (78) related the oxygen debt to the occurrence of lactic acid in the blood. Hill et al. were of the opinion that lactic acid plays an important role in muscular contraction, being the "stimulant" for contraction.

High concentrations of lactic acid in the blood was observed by many authors during and after exhaustive exercise (Margaria et al. (87), Bang (20), Robinson et al. (102), Friedeman et al. (58), Åstrand (15), among others). The concentration of blood lactate was taken as an index of exhaustion by Åstrand (14), whereas other authors interpretated it as an index of efficiency of oxygen transport to the working muscles (Holmgren (67), Holmgren and Ström (69), Donald et al. (47), Carlson et al. (33) and Harris et al. (62)).

(iii) Excess lactate

Huckabee (72, 73) indicated that blood lactic acid concentration is not a reliable index of anaerobic metabolism. He showed that factors such as hyperventiliation, changes of blood pH and blood pyruvate concentrations can lead to changes in blood lactate concentrations, while the same work loads are performed.

Other authors also found that such conditions as alimentation (Friedeman et al. (58), injection of adrenalin (Griffith et al. (60), glucose

injections (Bueding et al. (29), Bueding and Goldfarb (27)), and hyperventilation (Fenn et al. (54)), can alter blood lactate concentrations.

Huckabee (73) pointed out that as lactate may be formed in the organism from pyruvate according to the formula:-

$$\left[\text{Pyruvate}\right] \times \left[DPNH_2\right] \rightleftharpoons K \left[\text{Lactate}\right] \times \left[DPN\right],$$

the amount of lactate may increase or decrease with the amount of pyruvate which is found as a normal metabolite in the body. He therefore developed a formula with which lactate formed in excess of that resulting from pyruvate could be calculated as follows:-

$$XL = (L_x - L_o) - (P_x - P_o)\ L_o/P_o$$

where: XL denotes excess lactate,
L denotes lactate concentrations,
P denotes pyruvate concentrations,
o denotes resting values and
x denotes values during work.

Huckabee demonstrated in a series of experiments that excess lactate values are found at all levels of exercise and that there is a close

relationship between excess lactate and oxygen debt. When lactate was expressed as "total excess lactate" he found that the value of oxygen debt and oxygen equivalent of total excess lactate were almost identical at any time during recovery from light to heavy work. Under the same circumstances the values of total lactate were significantly different from the oxygen debt figures.

The concept of Huckabee presupposes that there is a uniform distribution of lactate throughout the total body fluids. Eggleton and Evans (51), however, indicated that a concentration gradient of lactate exists between muscle and plasma during exercise. Decker and Rosenbaum (42) reported that lactate concentrations in cells and plasma are equivalent in the resting state. They did, however, demonstrate a higher concentration of lactate in plasma as compared to that in cells under conditions where blood lactate levels were increased above resting values. Huckabee (71) found a concentration gradient between plasma and cells during rest and exercise, with lactate concentrations dominating in the plasma.

Harris and colleagues (62) criticized the concept of "excess lactate" as they could not demonstrate a linear and indefinite increase in "excess lactate" relative to time.

Thomas and others (113) substantiated the above findings by indicating that "excess lactate" is a variable rather than a constant factor with respect to time. Margaria and co-workers (86) also criticized Huckabee's concept, as at low levels of oxygen intake an oxygen debt may be present without a subsequent increase of lactate concentration. It should be pointed out, however, that Margaria's observations were based on experiments done on venous blood, whereas Huckabee worked on arterial blood. Knuttgen (81) worked on blood from the hyperaemic fingertip and came to similar conclusions as Margaria et al. (86).

Differences in lactate content of blood, sampled simultaneously from veins, arteries and capillaries were reported by different authors (Barr and Himwich (22), Eggleton and Evans (51), and Pernow and Wahren (98)). Grimby (61) reported that blood from the hyperaemic fingertip had a lactate content similar to that of arterial blood.

5. RESTING VALUES OF LACTATE AND PYRUVATE

Resting values of lactic acid, as determined by the method of Barker and Summerson (21), was found to be different by various authors. Values ranged from 0.62 to 1.03 mM per litre blood water according to reports in the literature by Goldsmith (59), Decker and Rosenbaum (42) and Huckabee (72).

The same holds true for blood pyruvate. Values of from 0.045 to 0.142 mM per litre blood water was quoted by different authors as the resting value (Platt and Lu (99), Bueding et al. (31), Friedemann et al. (58), Goldsmith (59) and Huckabee (72)). The above-mentioned rather large variations are probably due to different blood sampling techniques, sampling sites and resting states.

Friedemann et al. (58), in a study on laboratory workers, showed that blood pyruvate and lactate values fluctuate to a minor extent during light work. Their study, however, indicated a rise in concentrations after meals rich in carbohydrate, during muscular activity and anoxia.

Furthermore, Bueding and Wortis (30) indicated that addition of perservatives to blood can alter significantly the concentration of the mentioned metabolites.

It was also demonstrated that the lactate/pyruvate ratio was changed in shed blood, mainly due to glycolysis (Bueding and Wortis (30), Huckabee (71)).

6. LACTATE AND PYRUVATE CONCENTRATIONS DURING WORK

Light work induced no increase in blood lactate values in studies done by Jervell (78), Owles (95) and Bang (20), whereas moderate work elicted slight increases in blood lactate concentrations. With hard and very hard work, however, rapid increases in blood lactate result. Extremely high values have been found during maximum work by Bang (20), Asmussen et al. (9), and Åstrand (14), among many other reports in the literature.

Bang (20), who studied the course of lactate concentrations during moderate work reported a "primary" rise in lactate which occured within the first five minutes of work. This was followed by a steady fall in lactate concentration during the work period. A "steady state" in lactic acid, as reported by Hill and colleagues (66), was not demonstrated. This finding was substantiated by several authors, among whom were Irma Åstrand (10), Donald and others (47), Grimby (61), and Harris et al. (62). On the other hand, Asmussen (7) and Huckabee (73) reported a steady rise of lactate during work relative to time.

The level of work at which anaerobic metabolism commences has been a controversal point in the past. Oxygen intake values of 1.0, 1.8 and 2.1, and between 1.2 and 2.1 litres per minute above resting oxygen intake values have been reported by Newmann and co-workers (93), Owles (95), and Taylor (110), respectively, as the level of work where anaerobic metabolism occurs. Margaria (87) related the lactic acid accumulation point to the individual's metabolic rate and reported that lactate started to accumulate at work loads requiring about 66 per cent of the maximum metabolic rate.

Wyndham et al. (121) reported that a level of 55 per cent of an individual's maximum capacity seems to be the maximum point at which work can just be performed under aerobic conditions.

Williams and others (117), however, showed recently that the point of anaerobic metabolism of highly trained individuals was at about 68 per cent of maximum capacity.

Furthermore, they pointed out that the onset of anaerobic metabolism was dependent on the individual's state of training. In the untrained individual the relevent level was found to be about 40 per cent of aerobic capacity, which could be changed through training to about 70 per cent of capacity.

The onset of anaerobic metabolism is also influenced by environmental conditions. Williams and co-workers (115) demonstrated that lactate increased at lower levels of work in heat than in comfortable conditions. This observation was explained as being due to more blood being shunted to the skin for heat dissipation purposes and, therefore, less blood being available for the transport of oxygen to the active muscles. Earlier studies done by Dill and colleagues (43) and by Robinson et al. (101) indicated the same trends.

7. CHANGES IN EXCESS LACTATE DURING WORK

Huckabee (73) reported that there was a linear increase in excess lactate throughout the entire period of exercise. This occured even at low work intensities. These findings were opposed by Williams et al.(115), Wyndham et al. (121) and Knuttgen (81), who worked on arterialized peripheral blood and found that at light and moderate rates of work no "excess lactate" was formed. Cobb and Johnstone (39) found an insignificant or no increase of excess lactate in subjects working at an oxygen intake level of 2.0 litres per minute. Harris and co-workers (62) showed that a plateau, or in some cases a peak, in excess lactate was

reached during work, followed by a gradual decline during the latter part of work. Similar observations were made by Carlson and Pernow (32), Carlson and others (33), Pernow and Wahren (98), Cobb and Johnstone (39) and Hood et al. (70) during studies on arterio-venous differences of "excess lactate".

8. THE HEART RATE/LACTATE RELATIONSHIP

It was observed that lactate starts to accumulate in blood when work of a certain intensity is performed. Wells and colleagues (114) related heart rate to lactic acid, and reported that for untrained men blood lactic acid increase if a work rate is performed which causes a heart rate response of between 120 to 140 beats per minute. Holmgren and Ström (69), in their study on well-trained cyclists, reported that lactate concentrations in blood rose when heart rates reached about 145 beats per minute. The corresponding values for untrained men were between 115 and 120 beats per minute. In a study performed on a bicycle ergometer while using one leg only, Carlson and Pernow (32) reported heart rates of 90 - 110 beats per minute for increases of lactate above resting values. Duner (49), however, indicated that work with one leg at a specific work rate showed higher blood lactate values than while working with both legs, a factor which may have contributed to low heart rate values as reported by Carlson and Pernow (32). Furthermore, Duner demonstrated that individual aerobic capacities were lower during work with one leg than when using both legs.

Williams et al. (117) found, in agreement with the findings of Wells and others (114), that increases in lactic acid occured in well-trained individuals who performed a rate of work which gave rise to heart rates of 120 - 140 beats per minute. It should be pointed out, however, that experiments done by Williams et al. were performed at an altitude of 4,750 feet above sea level.

It is a well-known fact that maximum heart rate values are lower at altitude than at sea level, with the result that heart rate response for the same level of work at sea level might be higher than the said 120 - 140 beats per minute.

9. PHYSICAL FITNESS

Dill and others (45) showed that the lactic acid response of unfit individuals to a certain work load is higher than for fit individuals. It was shown by Robinson and Harmon (103) that a training regime lowered the lactate response of an individual to a certain work load. They also indicated that well-trained individuals could endure higher lactate values than untrained persons during maximal work. The studies of Holmgren and Ström (69) demonstrated that the blood lactate value was significantly lower for physically fit subjects at a given heart rate, then for unfit subjects. Comparisons done on groups of fit and unfit subjects substantiated the above findings (Cook and Hurst (40), Newmann et al. (93), and Åstrand (14)).

10. PROLONGED WORK

As far back as 1923, Hill and Lupton (66) stated that the oxygen requirements of the working muscles should be balanced by the oxygen intake if work is to be performed for prolonged periods. In other words, aerobic processes should supply all the energy neccesary for muscular contraction during all phases of prolonged muscular work.

Numerous studies have since been done on prolonged work, but most of the studies had a common shortcoming in that work was not done continuously for a whole normal shift of eight hours duration.

Irma Åstrand (10), for instance, did an experiment during which subjects worked alternately on a bicycle ergometer and on a treadmill. The subjects had a rest period of 10 minutes after every hour of work, as well as a lunch break of one hour. Under the above circumstances she demonstrated that blood lactate was unchanged after seven hours of work at an oxygen intake of about 50 per cent of the individual's aerobic capacity.

Wyndham et al. (121) reported that work at a limit of 55 per cent of aerobic capacity could be sustained daily for prolonged periods. These findings were based on tests done on a bicycle ergometer over periods of about seven minutes. It is doubtful, however, if these results can be applied to endurance work lasting up to eight hours. According to their findings the accumulation of excess lactate in the blood was the limiting factor for endurance work. This, however, is true for heavy exercise which can be endured only for short periods.

Studies done by Bang (20), Cobb and Johnstone (39) and Donald et al. (47) indicated that there was an initial peak in blood lactate with a progressive decrease thereafter during prolonged constant work. Sampling of blood during this "peak" period in lactate concentrations could have led to the high "excess lactate" values found by Wyndham et al. (121) during their experiments at submaximal work loads. This may well led to an underestimation of the point at which individuals went into anaerobic metabolism as indicated by an increase in "excess lactate". Williams et al. (116) pointed out that the subjects used in the study by Wyndham and others were not highly trained, which could also have contributed to the rather low figure cited. It was pointed out earlier (117, 118) that the "excess lactate" and lactate turnpoint is dependent, amongst other factors, on the state of training of the individual. Other factors such as age (14) and ambient temperature (115) may also influence the point where an individual will show an increase in lactate and "excess lactate" over pre-exercise levels.

Williams and colleagues (116) in a study on highly trained men showed that the optimum level of oxygen consumption, expressed as a percentage of the maximum at which men could work without an increase in blood lactate, was 67.8 per cent. The corresponding value for "excess lactate" was found to be 69.0 per cent.

Michael and co-workers (89) indicated that a work rate equivalent to 35 per cent of aerobic capacity could be sustained for periods of up to eight hours per day without

increases in blood lactate. Work at 75 per cent of the aerobic capacity caused slight increases in blood lactate values at the end of three hours of continuous work in a study done by Saltin and Stenberg (106). Åstrand et al. (15) indicated that lactic acid in blood was raised to above twice that of resting values during competitive skiing lasting about eight and a half hours.

Different investigators of "prolonged" work, such as Grimby (61), Cobb and Johnstone (39), Irma Åstrand (14) and Irma Åstrand et al. (13), showed that blood lactate values were higher during the initial stages of exercise than those observed during the final stages of work, if work leads were low enough to be sustained for prolonged periods.

CHAPTER 3

METHODOLOGY

1. SELECTION AND TRAINING OF SUBJECTS

Four healthy young Bantu males, recruited to the South African gold mining industry, were used as subjects. The physical characteristics of the subjects, at the end of a period of training, are presented in Table I.

TABLE I

SUBJECT	WEIGHT, kg	HEIGHT, cm	SURFACE AREA*, m^2
DA.	60.35	163.4	1.65
MA.	75.90	177.0	1.93
ZE.	61.65	163.2	1.66
FR.	57.20	169.3	1.66

The subjects were in the age group 18 to 25 years.

The subjects were trained for a period of about two months before the main experiment commenced. The training consisted of pedalling on a constant work load bicycle ergometer. They were required to pedal at a load producing an oxygen intake of approximately 50 per cent of their maximum oxygen intakes for a period of four hours per day, for six days per week. Heart rates were recorded,

---

* Calculated according to Du Bois and Du Bois (48).

with an electrocardiograph to determine whether a "steady state" in heart rate was maintained during the whole period of training. In the afternoons the training consisted of pedalling at work loads requiring oxygen consumption values of approximately 80 per cent of their maximum oxygen intakes. They pedalled at this rate until exhaustion forced them to stop. This was then followed, after a half-an-hour period of rest, by a maximal effort for as long as possible.

The outlined training programme was performed for at least two months prior to the experiment. All subjects were considered highly trained and in an optimum state of physical fitness before the main experiment commenced.

They worked on a bonus system during the actual experiment; this was found to motivate them to a high degree, especially for endurance work which lasted in some instances up to eight hours per day.

2. SELECTION OF WORK RATES

The load at which the subjects could continue for a period longer than eight hours was taken as the lowest load. The loads were then increased at intervals of a thousand foot pounds per minute up to the level where work could be performed for about 20 minutes. Additional work loads were performed to establish a reliable endurance time/work load curve. The maximum oxygen intake values of the individual subjects were determined during the final stage of the experiment.

3. TEST PROCEDURE

The subjects came to the laboratory early in the morning in the post-prandial state. They were rested in the supine position for at least two hours before observations of resting values were made. The parameters measured were resting oxygen intake, heart rate, blood lactate and pyruvate values, as well as blood glucose. The subjects were then required to work at a certain work rate on a constant work load bicycle ergometer. The rate of work performed was not disclosed in order to eliminate the psychological effect of the performance times achieved on previous days.

The experimental runs lasted for a maximum period of eight hours, or until fatigue compelled the subjects to stop pedalling. Water was allowed ad libitum during the work period. Urine was passed, if neccesary, while busy performing pedalling. No allowance was made for subjects to defecate during the work period.

Samples of expired air were collected over a period of five minutes for the resting observation and over three minutes during work at the second, fourth, sixth and eighth hour of each experimental run. In cases where the subjects could not work for the maximum period, a terminal sample of three minutes was taken immediately before the subject stopped work.

Blood samples for lactic and pyruvic acid analysis were taken at intervals of two hours of work and a terminal sample was taken just before the subject was compelled to stop due to exhaustion. Blood for the determination of

blood glucose concentration was taken concurrently with that for the determination of lactic and pyruvic acids.

Rectal temperatures were recorded at rest, after 15 minutes of exercise and from then onwards at hourly intervals up to the terminal sample.

Heart rates were recorded at rest, after 15 minutes of exercise and then hourly until the last sample before work was discontinued.

A. Gas sampling

Gas samples were collected utilizing the conventional Douglas bag method. Corrugated rubber tubing with a wide bore (1½ inch diameter) was used to minimize resistance. An Edwards mask, fitted with two Max Planck low resistance valves, was used. These valves were shown to be the most efficient functioning valve with a low resistance (119). The mask was put on to the subject's face one minute before the gas sample was taken, in order to wash out all atmospheric air from the mask and the corrugated tubing. The expired air was collected in a hanging Douglas bag, which had previously been flushed with air.

From the Douglas bag two aliquot samples of expired gas were collected in butyl rubber bags of 1.5-litre capacity. These gas samples were analysed for oxygen, nitrogen and carbon dioxide content: the volume of the remainder of the gas in the Douglas bag was measured by means of a Collins chain-compensated gasometer of 350-litre capacity. To the volume, as measured by the spirometer, 3 litres were added to account for the samples taken

for analysis. The volume of expired air was corrected to S.T.P.D.

B. Collection of blood samples

Blood was sampled according to the method of Huckabee (71). The technique requires that the weight of the sampled blood be used for determination of the contents and not the volume. Bueding and Wortis (30), and Huckabee (71) indicated the glycolysis occurs rapidly in shed blood; therefore, the blood was allowed to flow directly into a receiving vessel. Deproteinization of blood was thus practically immediately completed.

Blood samples were taken in the following manner: the subject's hand was warmed for at least five minutes in a water bath at 49 $\pm$ 0.5°C before blood was taken. The fingertip was dried with a towel, greased with petroleum jelly, and a cut made with an automatic spring stiletto. It was neccesary to squeeze the fingertip to a slight extent in a distal direction to obtain enough blood for analysis. The first drop of blood was discarded. All samples were taken well within a period of 10 seconds.

(a) Blood for lactic and pyruvic acid determinations

Fifteen milliliter aliquot samples of a 10 per cent (w/v) aqueous trichloroacetic acid solution was measured into glass weighing bottles by means of a burette. Evaporation of the liquid was prevented by sealing the lids of the bottles with silicone grease. The bottle plus contents was weighed

accurately to four decimal places. About 0.5 gram of blood was collected while the bottle was gently agitated to ensure complete deproteinization of blood. The vessel was closed immediately thereafter and weighed again to determine the amount of blood taken. The contents was then contrifuged at 5,000 r.p.m. for 10 minutes and the supernatant set aside for analysis.

(b) Blood for blood glucose determination

Ten milliliters of a 3 per cent aqueous solution of trichloroacetic acid was measured into a glass weighing bottle, sealed with silicone grease and weighed accurately to four decimal places. About 0.40 gram of blood was sampled in the same manner as described above, and re-weighed. The contents were then centrifuged for 10 minutes at 5,000 r.p.m. and the centrifugate set aside for analysis.

(c) Blood for percentage blood water

Blood was collected in pre-weighed glass crucibles together with every sample taken for lactate and pyruvate analysis. The crucible containing the wet blood was weighed again. The blood was dried in an electric oven at 110°F till constant weight was obtained, re-weighed and the percentage blood water calculated as follows:-

Weight of crucible empty ..... = a

Weight of crucible + blood (wet) .. = b

Weight of crucible + blood (dry) .. = c

$$\% \text{ blood water} = \frac{\text{b-c (weight loss)}}{\text{b-a (wet blood weight)}} \times 100$$

C. Heart rate

Heart rate was measured with a portable Sanborn electrocardiograph over a period of fifteen seconds. A rubber band was fitted around the subject's chest at the level of the fifth intercostal space in order to keep the electrodes in position. RA and LA cardiographic leads, with RL as earth, were used.

D. Rectal temperature

Rectal temperature measurements were made with a copper-constantan thermocouple mounted in a polythene catheter, and recorded on a Leeds and Northrup vernier potentiometer. The thermocouple was inserted to a depth of 4 inches into the rectum.

E. Measurement of aerobic capacity

The maximal oxygen intakes of the four subjects were determined according to a method previously described by Wyndham et al. (119). This technique involves the measurement of oxygen intake at increasing rates of work until no further increase in oxygen intake occurs with increase in load.

The level of work was increased by 1000 foot pounds per minute from an initial 4000 foot pounds per minute up to each individual's respective maximum effort. Oxygen intakes were measured from the 6th to the 9th minutes at submaximal levels of work, or from the 5th to the 7th minutes when the subject was unable to complete 9 minutes of work. At levels of work associated with the individual's maximum oxygen intake the duration of work was usually only three minutes. At these levels of work expired air was therefore collected from the second to the third minute of work. At least three repeat observations on different days were made of heart rate and oxygen intake at each level of work for each test subject.

4. ANALYTICAL METHODS

A. Gas analysis

Expired air was analysed for oxygen, carbon dioxide and nitrogen content on a Beckman E2 paramagnetic oxygen analyser (97). Use was made of a mechanical suction pump to ensure a constant flow of gas through the instrument. Gas to be analysed was dried over anhydrous magnesium perchlorate contained in a U-tube connected in series with the apparatus to its inlet side. A second U-tube, filled with dry Ascarite, a sodium hydrate asbestos absorbent, connected in series to the first U-tube was used for the determination of carbon dioxide content. The percentage CO_2 was calculated according to the following formula:

$$\text{per cent } CO_2 = \frac{\% \text{ oxygen with } CO_2 \text{ removed} - \% O_2}{\% \text{ oxygen with } CO_2 \text{ removed}}$$

In order to keep errors to an absolute minimum, a technique of duplicate gas analysis by two observers was employed, as previously reported by Strydom et al. (108).

B. Lactic acid

The analysis of blood lactic acid content was carried out according to the method of Barker and Summerson (21), as modified by Hullin and Noble (74), and Strőm (109).

(a) Reagents

i. Phenol red indicator;

About 1 gram of phenol red was dissolved in 50 ml of absolute ethyl alcohol and filtered before use.

ii. Cupric sulphate;

A 20 per cent aqueous solution was made up by dissolving 20 grams of cupric sulphate ($CuSO_4.5H_2O$) in 100 ml of distilled water.

iii. Lithium hydroxide;

Crystalline lithium hydroxide was first dried in an electric oven at 100°C until a constant weight was obtained, and then about 20 gram of the dried powder was dissolved in 100 ml of distilled water to obtain a saturated solution.

iv. Sulphuric acid;

Analar grade concentrated sulphuric acid was used.

v. Ethyl alcohol;

Commercial grade alcohol of 96% purity was used.

vi. Sodium hydroxide;

A 2% aqueous solution was made up by dissolving 2 grams of sodium hydroxide in 100 ml of distilled water.

vii. Para-hydroxy-diphenyl;

About 1.5 grams of para-hydroxy-diphenyl was dissolved in 100 ml of an aqueous 2% solution of sodium hydroxide. The resulting solution was filtered through a sintered glass filter before use.

viii. Lactate standard;

Exactly 0.2133 gram of pure lithium lactate (see below for preparation) was dissolved in 100 ml distilled water in a one litre volumetric flask. One milliliter of concentrated sulphuric acid (Analar grade) was added to this. The volume was then made up to one litre with distilled water, and the solution was mixed thoroughly. This was the stock solution containing 0.2 mg lactic acid per milliliter.

A working standard was prepared by diluting 10 ml of the stock solution to 200 ml with distilled water in a volumetric flask. This solution contained 0.01 mg lactic acid per milliliter (10 µg/ml).

Pure lithium lactate was prepared as follows:-

An aqueous solution of 85% U.S.P. lactic acid was diluted with an equal volume of distilled water and a few drops of phenol red indicator were added. Saturated 20% lithium hydroxide was added, using a pipette, to a slight excess as indicated by the phenol red indicator. The solution was then heated to boiling point and lithium was again added to a slight excess. The solution was then cooled at room temperature and filtered through a sintered glass filter. Four volumes of 96% ethyl alcohol were added and the mixture was cooled overnight in a refrigerator. The crystals of lithium lactate which had formed were collected by filtering the mixture through a Buchner funnel. The crystals remaining on the filter paper were washed thoroughly with 96% ethyl alcohol, and recrystallized with distilled water and dried in an electric oven at 100°C. Lithium lactate was preferred because of its anhydrous and non-hygroscopic properties.

(b) Procedure

Five milliliters of concentrated Analar grade sulphuric acid was pipetted into each of a series of ground glass stoppered test tubes, the drainage time (15 seconds) being carefully controlled with the aid of a stopwatch. Two drops of a 20% (w/v) aqueous solution of cupric sulphate was added to each test tube and the contents of each test tube treated as follows:-

The test tube was placed in crushed ice and 1 ml of the supernatant fluid of the sample pipetted into it. The test tube was then quickly shaken to ensure that the deproteinized blood solution was well mixed with the

sulphuric acid, and returned to the ice to prevent the contents from becoming too hot. The tube was stoppered and put into a water-bath at 60°C (± 0.5°C) for exactly 30 minutes, after which it was cooled in crushed ice for 4½ minutes. Three drops of a 1.5% solution of para-hydroxy-diphenyl in 2% sodium hydroxide were then added and the contents of the tube carefully shaken once more to disperse the precipitated para-hydroxy-diphenyl in the concentrated sulphuric acid. The test tube was then transferred to a waterbath at 30°C (± 0.5°C) for 20 minutes, during which time it was shaken twice. The test tube was then placed in rapidly boiling water for exactly 90 seconds, after which it was once more cooled in crushed ice for 3 minutes. The percentage transmittance of the violet coloured solution was then read on a Beckman DU spectrophotometer at a peak wavelength of 560 mμ. Each blood sample was analysed in duplicate.

In addition a set of reagent blanks and standard solutions of known concentrations were prepared and treated exactly as described above. In the blanks 1 ml of a 10% (w/v) trichloroacetic acid solution was used and for the standards, 1 ml each of a 3 microgram per ml, a 5 microgram per ml and a 8 microgram per ml lithium lactate solution was used. These standards were prepared by taking 0.3, 0.5 and 0.8 ml of the working standard solution described earlier, respectively, and making the volumes up to one ml in each case with 10% trichloroacetic acid.

(c) Calculation

The optical densities of the standards and unknown sample solutions were determined by dividing the percentage transmittance of the solution into the mean percentage transmittance of the reagent blanks and taking the logarithm of the result. A standard curve was then constructed by plotting the optical densities of the standard solutions against their known lactate concentrations. This curve took the form of a straight line passing through the origin of the graph, and from it the lactate concentrations of the unknown solution could be read off.

The lactate values obtained from the graph were then multiplied by the number of milliliters of trichloroacetic acid used in the sampling bottles - in this case, 10 ml. The answer was the amount of lactate, expressed in micrograms, present in the sampling bottle. Since each sampling bottle contained a known weight of whole blood, and the percentage blood water present in the blood at the time of sampling had been determined, the weight of blood water present in each sampling bottle could be calculated by multiplying the weight of blood by the percentage blood water.

By dividing the total lactate determined for each sample by the weight of blood water in the sample, the number of milligrams lactate per litre blood water could be calculated. This value was then divided by 90 (the molecular weight of lactic acid) in order to express the final result as millimoles lactate per litre blood water.

C. Pyruvic acid

The analysis of pyruvic acid was done according to the method of Friedemann and Haugen (57), with modifications by Huckabee (71).

(a) Reagents

i. 2-4-Dinitro-phenyl-hydrazine reagent;

Exactly 0.25 gram of the powdered substance was ground in a mortar and dissolved in 100 ml concentrated hydrochloric acid in a 500 ml volumetric flask. The volume was made up to the mark with distilled water and filtered through Whatman No. 40 filter paper. The solution was kept in a refrigerator.

ii. 10% Trichloroacetic acid;

One hundred grams of the crystals were dissolved in distilled water in a one litre volumetric flask and made up to the mark with distilled water.

iii. Xylene;

Commercial grade xylene was filtered through multi-layered filter paper to remove all traces of water.

iv. Distilled water;

The necessary quantity was prepared with a de-ionizer.

v. Sodium carbonate;

An aqueous solution was prepared by dissolving 90 grams of sodium carbonate in distilled water in a one litre volumetric flask.

The solution was left standing for complete dissipation of heat caused by the reaction with water, and then made up to the mark.

vi. Sodium hydroxide;

A normal solution was prepared by dissolving 20 grams of sodium hydroxide pellets with distilled water in a 500 ml volumetric flask. It was made up to the mark after all generated heat was dissipated.

vii. Standard pyruvate;

Exactly 0.1239 gram of sodium pyruvate was dissolved in 20 ml distilled water. This was the stock solution and was prepared once a week.

A working solution of sodium pyruvate was made by transfering one ml of the stock solution to a one litre volumetric flask and the volume made up to the mark with distilled water. This working standard then had a concentration of 5 micrograms per milliliter, the impurities of the reagent being taken into consideration.

(b) Procedure

Reagent blanks were prepared by pipetting 3 ml of a 10% trichloroacetic acid solution into two test tubes. The standard concentrations used in the analyses were 5, 10 and 15 micrograms per 3 ml, respectively. These were made up by taking 1, 2 and 3 ml of the working standard solution and making it up to 3 ml with 10% trichloroacetic acid, respectively.

Three aliquots of one milliliter each of the supernatant fluid previously set aside for analysis, were then pipetted into test tubes. All analysis of the contents of the test tubes, described, were done in duplicate as follows:

Two milliliter aliquots of the 2-4-dinitrophenyl-hydrazine solution were pipetted into each test tube. The test tubes were allowed to stand for about 5 minutes, and then 4 ml xylene was added by means of a burette. Nitrogen gas was then bubbled through the contents of the test tube in a fume cupboard for exactly one minute, the gas flowing at a rate of 3 litres per minute. After the two immiscible fluids seperated, the bottom layer was removed by means of a Pasteur pipette and discarded. Five milliliters of the sodium carbonate solution was then added to the solution and nitrogen gas again bubbled through for one minute. The bottom layer was then transferred to a clean test tube utilizing the same Pasteur pipette which had been cleaned thoroughly with sodium carbonate solution. Four milliliters of xylene and 2 ml sodium carbonate solution were then added to the original test tube by means of burets and again bubbled through for one minute. The bottom layer was then completely extracted into a second series of test tubes. From these test tubes 4 ml were pipetted into a centrifuge tube containing one ml 1 N sodium hydroxide.

The centrifuge tube was agitated by hand to ensure mixing of the two solutions and then centrifuged for three minutes at 5,000 r.p.m. The samples were read on a Beckman DU spectrophotometer against distilled water at a peak wavelength of 520 mμ.

A calibration curve was fitted for the standards, utilizing the logarithm of the optical density and the known concentrations of pyruvate. The concentrations of the unknown samples were then read from this graph and related to the original sample weights. The results were expressed as millimoles pyruvate per litre of blood water.

D. BLOOD GLUCOSE

Analysis of blood glucose was done according to the method of Hultman (75) as modified by Hyvärinen and Nikkilä (76).

(a) Reagents

i. 3% Trichloroacetic acid;

Thirty grams of the crystals were dissolved in distilled water in a one litre volumetric flask and made up to the mark with distilled water.

ii. Colour reagent;

About 2 grams of thiourea was dissolved in 900 ml reagent grade glacial acetic acid, and 100 ml of o-toluidine was added and thoroughly mixed. The reagent was stored away from direct sunlight in a brown container.

iii. 0.2% Benzoic acid solution;

This was prepared by diluting 0.2 gram of benzoic acid to 100 ml in a volumetric flask with distilled water.

iv. Glucose standard;

Exactly one gram of d-glucose was dissolved in 0.2% benzoic acid solution and made up to the mark in a one litre volumetric flask. This solution contained 100 mg glucose per 100 ml benzoic acid solution.

(b) Procedure

Reagent blanks were prepared by pipetting 0.5 ml of a 3% trichloroacetic acid solution and 4 ml of the colour reagent into two test tubes. The glucose standard was prepared by pipetting 0.5 ml of the standard solution into duplicate test tubes containing 4 ml of colour reagent.

For the determination of blood glucose 0.2 ml of whole blood was added to exactly 2 ml of 3% trichloroacetic acid and gently shaken. After a few minutes standing it was centrifuged at 5,000 r.p.m. Exactly 0.5 ml of the centrifugate were then pipetted into duplicate test tubes containing 4 ml of colour reagent and thoroughly mixed by gentle agitation. The test tubes were then put into boiling water for eight minutes and then allowed to cool at room temperature. The developed blue-green colour of the samples were then read on a Beckman DU spectrophotometer against distilled water at a peak wavelength of 630 mμ.

(c) Calculation

Blood glucose concentration in mg per 100 ml was calculated according to the formula:

$$\frac{\text{Optical density unknown}}{\text{Optical density standard}} \times \frac{\text{volume used}}{\text{volume blood taken}} \times 100$$

The volume of blood taken was obtained by dividing the weight of blood taken into the S.G. of blood, taken to be 1.06. The final form of the equation will then be:

$$\frac{\text{O.D. test}}{\text{O.D. standard}} \times \frac{0.53}{\text{weight blood taken}} \times 100 = X \text{ mg\%}$$

5. THE BICYCLE ERGOMETER

The bicycle ergometer employed in the present study was developed and built by the Electronics Division of the Chamber of Mines of South Africa Research Laboratories. The ergometer was specifically designed to maintain a constant work rate, irrespective of pedalling rate. It was established that a 10 per cent change in pedal speed resulted in an error of only 2 per cent in the work load performed. A detailed description of this ergometer has been given by Atkins and Nicholson (19).

Despite the fact that the bicycle ergometer is a constant work load instrument the pedal rate was maintained at 60 revolutions per minute; the pace of pedalling was indicated by a sound metronome.

6. STATISTICAL ANALYSIS

Statistical analysis of results was made by calculating confidence limits for the different values.

This involves an estimation of the value of a population parameter from information contained in a sample drawn from that population. Where there are no changes in the population over time (and we assume that there are none), the population mean, or any other population parameter, may be regarded as a constant; the task of the investigation is to estimate its value. Any specific estimate is either true or false, and, therefore, probability considerations must enter into the estimating procedure, if we are to have any objective method for evaluating these estimates.

These estimates are normally intervals rather than points. It is essential to evaluate these estimates in terms of probabilities, because there is no probability associated with a point for continuous distributions. Moreover, the degree of confidence that such an interval includes the true population mean is measurable, and is numerically equal to the percentage of such intervals, if many were to be computed by the same procedure, which may be expected to include the true mean.

These intervals are called confidence intervals of limits (referring to the upper and lower limits of such an interval). Three different degrees of confidence are commonly used in statistics, namely 90, 95 and 99 per cent. By convention 95% confidence limits are by far the most commonly used in statistical inference.

In the case of 95% confidence limits used in this study, the probability that the true population mean falls within the limits is 95%, and the probability that it falls outside these limits is only 5%.

If one refer to some of the figures it seems in some instances if the confidence limits do overlap, while a significant increase or decrease in the parameter was calculated. It should be pointed out that the 95% confidence limits plotted are interval estimates of the mean value of the parameter. For instance, a high correlation exists between heart rates measured at different times and therefore much narrower limits could be obtained for the mean differences in heart rates (based on paired values) between different times. Consequently it was often possible to show that a significant mean difference exists between heart rates measured at different times, at the 5% level of significance, although the 95% confidence limits, which were not based on the paired values, do overlap.

CHAPTER 4

RESULTS

A comparison was made of the physiological responses of men while they performed work, ranging from light to heavy rates of work, until they were compelled to stop work due to exhaustion. The values of oxygen intake, blood pyruvic acid, blood lactic acid and blood glucose were generally determined after two hours of work. This was then followed by observations made at the end of every two-hour period during a period of eight hours of continuous work. Terminal observations were made just before the subject stopped work, due to exhaustion, and the tolerance time noted. Measurements of heart rate and rectal temperature were made after 15 minutes of work, and again at the end of each hour until work was terminated. The value of "excess lactate", derived from blood lactate and pyruvate concentrations, was calculated in all cases where these observations were obtained.

1. MAXIMUM CAPACITY OF SUBJECTS

At least three determinations of oxygen intake values were made at various work loads during the latter part of the experiment, in order to determine the maximum capacities of the subjects. At least three repeat experiments were done at every work load to ensure reliable values. The results obtained on the four subjects are presented in Figure 1.

The maximum capacities of three of the subjects (DA, ZE and FR) were all about 3 litres per minute, and thus very similar. Subject MA, however, had a maximum capacity of 3.75 litres per minute. These values expressed in ml per kilogram body weight per minute, represent maximum capacity values of 47.0, 49.4, 51.4 and 52.9 for subjects ZE, MA, DA and FR, respectively.

2. RELATIVE WORK LOAD

In Figure 2 is presented the levels of oxygen consumption at various work loads relative to time. The work loads varies from light to heavy work. A statistical comparison between the oxygen intake value after nine minutes of work (in some cases after two hours of work) and the terminal value, which was measured just before work was discontinued, showed that there was no significance. On these grounds, an average value of the oxygen consumption values measured during the course of work could be used to calculate the relative work load performed. The individual's mean oxygen intake during work, as compared to his maximum capacity, was expressed as a percentage of his maximum capacity. It was stated earlier that determinations of maximum capacities were made only during the latter part of the experiment. Consequently, work loads at exact percentages, for inctance 40, 50, 60 and 70 per cent of maximum capacity, could not be done.

The work loads performed in this study and the calculated relative work loads are given for each individual in Table II.

TABLE II

WORK RATE (ft. lb. per minute)	SUBJECT MA.		SUBJECT DA.		SUBJECT ZE.		SUBJECT FR.	
	O_2 Intake as a % of Maximum Capacity	Relative Load	O_2 Intake as a % of Maximum Capacity	Relative Load	O_2 Intake as a % of Maximum Capacity	Relative Load	O_2 Intake as a % of Maximum Capacity	Relative Load
4000					± 37.6 2.8%	40%	± 43.7 4.1%	40%
4500							± 47.6 2.1%	50%
5000	± 40.5 5.4%	40%	± 44.9 4.0%	40%	± 48.4 5.3%	50%	± 55.2 3.2%	55%
5500					± 53.1 6.5%	55%		
6000			± 53.3 4.1%	50%	± 64.3 8.1%	60%	± 62.1 3.8%	60%
6500	± 50.2 2.1%	50%	± 56.9 2.6%	55%				
7000	± 52.0 4.3%	55%	± 60.4 3.1%	60%	± 69.7 2.5%	70%	± 68.7 4.7%	70%
8000	± 60.8 3.7%	60%	± 68.8 0.8%	70%				
8500					± 82.5 2.3%	80%		
9000	± 67.0 4.1%	70%			± 86.2 0.7%	90%	± 83.5 3.0%	80%
10000			± 83.0 6.6%	80%				
10500			± 91.6 2.3%	90%				
11000	± 82.2 3.0%	80%						
12000	± 87.0 2.7%	90%						

3. STATE OF TRAINING

The "excess lactate" inflection point were determined for the four subjects. The relative, instead of absolute, work loads were used in order to determine the "inflection" point. The results are presented in Figure 3. This figure shows that the point at which excess lactate starts to increase is similar for three of the subjects (MA, DA and ZE), while that of the fourth subject indicated an increase at about 61% of his maximum capacity.

Williams et al. (121) considered the value of the inflection point as an indication of the state of training of an individual. Although subject FR followed an identical training regime before the commencement of the main experiment, the above findings presumably indicate that he was not as highly trained as the other three persons. Accordingly, the results obtained at different relative work loads for the three subjects MA, DA and ZE, are grouped together, while the results obtained for subject FR are dealt with separately.

4. PROLONGED WORK

Observations of changes in physiological parameters during the work period was made in order to determine whether any of the parameters were altered before work was discontinued due to exhaustion. A significant change in any particular parameter could throw more light on the problem of limiting factors in prolonged work.

4/10/1965.

HUMAN SCIENCES LABORATORY

MAXIMUM OXYGEN CAPACITY DETERMINATION

COMPANY NO. ..... Date .....

WEIGHT .....

RESTING OBSERVATION:-

Oral Temperature .....°F Heart Rate ...../min.

RATE OF WORK	HEART RATE 10 min. 15 min.	O_2 CONSUMPTION LITRES/MIN
6 Steps/min	...../½ min ...../½ min ...../min ...../min Mean ...../min	
12 Steps/min	...../½ min ...../½ min ...../min ...../min Mean ...../min	
18 Steps/min	...../½ min ...../½ min ...../min ...../min Mean ...../min	
24 Steps/min	...../½ min ...../½ min ...../min ...../min Mean ...../min	
24 Steps/min (15" Step)	...../½ min ...../½ min ...../min ...../min Mean ...../min	
30 Steps/min (15" Step)	...../½ min ...../½ min ...../min ...../min Mean ...../min	

MAXIMUM OXYGEN CAPACITY ..... litres/min.

(a) Heart rate

Figure 4 (a, b) illustrate the heart rate responses to work at various levels of oxygen consumption.

A statistical comparison between the heart rate value after 15 minutes of work and the heart rate value before work was terminated, indicated that there was a significant increase at the 5% level of confidence during the course of work at all work rates.

Heart rates were recorded in some instances after 9 minutes of work. A decrease in heart rate was observed between the 9th and the 15th minutes of exercise. This decrease in heart rate, although not significant, seems to indicate that a "steady state" in heart rate had not yet been reached after 9 minutes of work.

(b) Oxygen intake

The oxygen consumption values during prolonged work are given in Figure 5 (a, b). Statistical analysis of the oxygen intake values, obtained at the lower levels of work (60 per cent of maximum capacity and below), indicated that there was a significant increase (5% level of confidence) in oxygen consumption values between the 2nd-hour and the terminal observations. The increase at a 40 per cent load was significant at the 10% level. A comparison between the oxygen intake value just before work was terminated and the previous value indicated no significant difference at the 5% level.

(c) Rectal temperature

Figure 6 (a, b) illustrate the responses of body temperature during prolonged work. It is evident that there is a gradual increase in body temperature during the course of work, even at the lowest levels of work. The mean increase in body temperature from the first-hour obervation to the terminal observation was found to be significant at the 5% level for all work loads. There was, however, no marked increase in body temperature immediately before work was discontinued.

(d) Pyruvic acid

The levels of blood pyruvic acid remained constant at resting values or even at values below that during the course of work up to the point of exhaustion at submaximal levels of work. At work loads demanding more than 70 per cent of the individual's maximum capacity, there was a marked increase in blood pyruvic acid levels. This is presented in Figure 7 (a, b).

(e) Lactic acid

The blood lactic acid response during prolonged work at various levels of work is presented in Figure 8 (a, b). An increase of this metabolite in blood was found at levels of work requiring more than 70 per cent of the individual's maximum capacity. In view of the general belief that accumulation of lactic acid is the limiting factor in endurance work, it is of special interest to note that no abrupt changes in lactic acid concentration occured before work was terminated.

(f) Excess lactate

Excess lactate showed the same pattern as blood lactic and pyruvic acids, as indicated in Figure 9 (a, b). Anaerobic metabolism occured at levels of work higher than 70 per cent of maximum oxygen intake. No increase in excess lactate was noted immediately before work was stopped due to exhaustion.

(g) Blood glucose

Blood glucose was the only parameter that showed a continuous change during the course of work at submaximal work rates, (Figure 10 (a, b)). The 40 per cent load, which was endured for a period longer than eight hours, caused blood glucose values to decrease steadily and reach a steady level after six hours of work. All work rates which were endured for periods shorter than eight hours, resulted in a continuous decrease in blood glucose values to a level which was about 25 mg% lower than the resting values.

5. TOLERANCE TIMES

Separate curves relating the exercise tolerance times at various levels of oxygen consumption to percentages of the maximum oxygen intake, were compiled from results obtained on each subject. From Figure 11 it is clear that two of the four men (DA and ZE) could perform continuous work for a period of eight hours at levels of oxygen consumption up to 50 per cent of their aerobic capacities.

The other two subjects (MA and FR) could do eight hours of work at 46 and 43 per cent, respectively, of their aerobic capacities. Work at levels higher than 50 per cent of aerobic capacity led to decisive decreases in tolerance times for all subjects.

From the above data a mean tolerance curve was drawn in relation to different percentages of the subject's aerobic capacities (Figure 11). According to the mean curve, a rate of work requiring less than 40 per cent of an individual's aerobic capacity can be performed continuously for a period of eight hours. Work at about 70 per cent of the aerobic capacity, that is, the point where highly trained individuals go into anaerobic metabolism, could be sustained on the average for 120 minutes.

CHAPTER 5

DISCUSSION

The phenomenon known as fatigue is understood rather vaguely and different research workers have tried to define it without success. The purpose of this study, however, is not to define fatigue, but rather an attempt to demonstrate the exact relative contributions of a number of physiological parameters to the manifestation of fatigue. With this end in view, the changes in different physiological parameters, relative to time, were followed up to the point of exhaustion.

The capacity of an individual to perform exercise for a prolonged period is dependent, inter alia, on the efficiency of the oxygen transport system and the amount of available energy stores in the body.

There are large inter-individual differences in maximal capacity between subjects. The relative level of work performed by a subject is preferred to the specific work load, because the latter does not give an indication of the degree of stress imposed on the individual. The relative work load is the oxygen consumption required for a particular work load, expressed as a percentage of the individual's maximum aerobic capacity.

1. Oxygen intake

The oxygen intake values at 40 per cent of aerobic capacity showed no significant changes during a period of eight hours of continuous work.

At work loads, higher than 40 per cent of aerobic capacity, which could be endured for periods shorter than eight hours, the oxygen intake showed a significant progressive increase at the 95% confidence level. This increase in oxygen intake was found to be linear throughout the working period. An increase in this parameter at submaximal levels of work is not considered to be a limiting factor for prolonged work. I. Åstrand (10) interpreted an increase in oxygen consumption during work as being due to deterioration of muscular coordination, that is, more muscle groups are used because of fatigue towards the end of the work period.

Michael et al. (89) stated that an eight-hour period of exercise could be completed without undue fatigue if oxygen consumption during work remained below 1.4 litres per minute. This conclusion was made following a study on three males who had maximum oxygen uptakes of about 4 litres per minute.

Passmore and Durnin (96) have suggested that during an extended working period the oxygen uptake should not exceed that equivalent to 5 kcal/minute, or approximately 30% of the maximum uptake. This is considerably lower than the 55% and 50% of maximum oxygen uptake suggested by Wyndham et al. (121) and I. Åstrand (10), respectively.

The present study indicated that an eight-hour period of exercise could be completed without undue fatigue, whenever work loads require not more than about 43% of maximum oxygen uptake. This work load is somewhat higher than the 35% of maximum oxygen uptake suggested by Michael et al. (89).

2. Heart rate

The heart rate response during exercise is that of a continuous increase towards the point of exhaustion. The increase was found to be significant at the 5% level for all work loads, including the load that could be endured for more than eight hours (40 per cent of aerobic capacity). This finding is in agreement with the findings of Ekelund and Holmgren (54), who described a continuous increase in heart rate during work that could be endured for about 60 minutes. In their study, heart rates increased from 148 beats per minute after 10 minutes of work to 171 beats per minute after 60 minutes work. In the present study, the increase in heart rate at the load that could be tolerated for about one hour at 80 per cent of aerobic capacity was from 150 (15 minutes) to 158 beats per minute. The high heart rates recorded at the end of the work period in the study of Ekelund and Holmgren presumably indicated that their subjects were not highly trained.

Ekelund (52), in a study on a group of healthy male subjects pedalling a bicycle ergometer at about 63 per cent of aerobic capacity, found an increase in heart rate during the work period. He is of the opinion that the maintenence of stroke volume throughout the work period may be a limiting factor during prolonged exercise. The gradual increase in heart rate, as was found at all work loads in the present investigation, may be indicative of a decreased stroke volume. Measurements of cardiac output and stroke volume were, however, not made in this study. The validity of this hypotheses could thus not be examined.

The gradual increase in heart rate, in a study done by Saltin and Stenberg (106), was explained to be due to dehydration of subjects during exercise. Adolph (1) showed that a decrease of about 1.5 per cent in body weight caused by dehydration, involves an increased load on the circulation, which can be seen in an increase in the heart rate during work. This was also confirmed by Berggren and Christensen (23). No data on weight loss during prolonged work were obtained in the present study. The extent of dehydration at different work loads and the effect it may have had on the heart rate response during work could thus not be evaluated.

I. Åstrand (10), in a study on young women walking on a treadmill at a rate of work requiring 50 per cent of their aerobic capacities, found that heart rates tended to decrease throughout an eight-hour work period, although the decrease was not significant. The average heart rate was found to be 110 beats per minute at the 50 per cent load. For older men, Åstrand et al. (13) observed that a heart rate of 105 beats per minute corresponded to the 50 per cent load.

The present study indicated that a heart rate of 105 beats per minute after one hour of work and 120 beats per minute at the end of the shift corresponds to the "optimum" level of energy expenditure, which is in agreement with the findings of Michael et al. (89).

Practically all energy generated in the body is derived from carbohydrate and fat metabolism. The dissimilation of fat requires more oxygen for each unit of energy compared

with the combustion of carbohydrates; the difference being about 9.9 per cent (82). Christensen and Hansen (37), Ahlborg (3), and Havel et al. (63) demonstrated that the share of fat combustion in energy production is greater towards the end of prolonged work, resulting in an increase in heart rate. These findings could not be confirmed, because respiratory quotients were not determined in the present investigation.

Michael et al. (89) stated that heart rate should remain below 120 beats per minute if work is to be performed for eight hours per day without undue fatigue. Christensen (36) put this figure at 130 beats per minute, provided that work is performed under "normal" climatic conditions.

The present study indicated that well-trained individuals could perform work continuously for eight hours if the heart rate remained below 110 beats per minute. Heart rates of 120 and 130 beats per minute after 15 minutes of work resulted in tolerance times of 256 and 121 minutes, respectively, in the present investigation.

Davies and Harris (41) claimed that the "pulse deficit index", that is, the number of beats by which the heart rate during the first minutes of work falls short of the count during the second four minutes of exercise, gives a reliable evaluation of work output. They found that this "index" remained at zero at the lower levels of work while it increased steeply when work rates requiring an oxygen consumption of more than 1.8 - 2.0 litres per minute is performed. Although blood lactic acid concentrations were not determined in their study, they considered that an in-

crease in "pulse deficit" co-incided with the point where the individual went into anaerobic metabolism.

3. Body temperature

It was shown by Christensen (34) and Nielsen (94) that the body temperature during continuous work adjusts itself at a certain level which is proportionate to the energy output. Nielsen also showed that the body temperature during work is independent of the environmental climate within certain limits. The performance of work at different levels on the bicycle ergometer, in the present study, resulted in increased levels of body temperature with increases in work load, which is in agreement with the findings of the abovementioned authors.

There was a rapid increase in body temperature up to about 60 minutes of work, thereafter remaining at a certain level depending on the work rate. This finding is in agreement with that of Christensen (35). After this level of body temperature had been reached there was an insignificant increase in body temperature until the point of exhaustion was reached at work loads requiring 60 per cent or less of the individual's aerobic capacity. The increase in body temperature was more or less continuous when work loads higher than this level were performed.

I. Åstrand (10), in a study on four subjects performing prolonged work, found that the "50 per cent load" resulted in a body temperature of 100.4°F. Michael et al. (89) stated that an eight-hour period of exercise could be completed without undue fatigue if the individual's rectal

temperature remained below 38.0°C (100.4°F). The present findings are, however, at variance with the mentioned findings as the average rectal temperature of the subjects was found to be 99.9°F at the 50 per cent load. At the 40 per cent load there was a slight, linear increase from 99.0°F to 99.7°F from the first to the eighth hour of work.

The levels of body temperature reached in the present study, even at near-maximal rates of work, were not high enough to warrant its consideration as a limiting factor for work (120).

4. Lactic acid

Values of blood lactate showed no increase above resting levels during the performance of prolonged work at levels lower then 70 per cent of aerobic capacity. The values in fact decreased at the lower levels (40 to 60% of aerobic capacity) during the course of work. This finding is in accordance with I. Åstrand (10), who found a decrease from 14 to 9 mg% in blood lactate values of subjects that performed prolonged exercise from the start to the end of work.

The present findings are, however, not in agreement with those of Fox et al. (56), Williams and co-workers (116) and Wyndham et al. (121), who stated that an increase in blood lactate content would be the limiting factor for prolonged work. Williams and co-workers (116) showed that a heart rate response of 142 beats per minute after 60 minutes of work co-incided with increases in blood lactate.

This finding is in accordance with that of the present study, because the 70 per cent load, at which an increase in blood lactate was observed, resulted in a heart rate response of 137.7 ± 9.0 beats per minute after 60 minutes of work. The assumption made by Williams et al. that men can work at a heart rate of up to 140 beats per minute for prolonged periods, however, was not confirmed in the present study. This study indicated that work could be tolerated for about two hours at the point where lactic acid started to increase above resting values. The accumulation of lactic acid in the body thus does not seem to be the limiting factor for prolonged work at levels of work below 70 per cent of the individual's maximum capacity.

5. Pyruvic acid

The blood pyruvate concentration showed slight or no variations during the course of work at work loads requiring less than 70 per cent of the individual's aerobic capacity. At work levels above this limit there is a continuous increase relative to time in conjunction with lactic acid values. The responses were similar to that of blood lactate with no accumulation towards the end of the work period.

6. Excess lactate

This parameter behaved in a similar manner as blood lactate and pyruvate values during prolonged work. Excess lactate remained at zero level throughout the entire work period if the levels of work being performed required less than 70 per cent of the individual's aerobic capacity.

An increase in excess lactate, indicating the onset of anaerobic metabolism (32), occurred at work levels requiring 70 per cent or more of the individual's aerobic capacities.

7. Blood glucose

The determined values of blood glucose showed a steady decrease below resting levels relative to time, irrespective of the work load performed. This finding is in accordance with the findings of Ahlborg (5) and other reports in the literature (79, 100, 107, 122). Edwards, Margaria and Dill (50) reported that for as long as exercise was continuous and the reserves of carbohydrate remained ample, blood sugar levels were maintained near the resting level presumably through an increase in glycogenolysis to a rate that was equal to the rate of carbohydrate oxidation. They found that four hours of hard work could be carried out before marked hypoglycaemia developed. Rodahl et al. (105), and Young and colleagues (122) maintained that the degree of exercise fatigue was dependent on the blood glucose content; this was substantiated by Ahlborg (2). Blood glucose values, in the present study, also decreased considerably during the course of exercise, and towards the end of the exercise period symptoms of fatigue were associated with symptoms of hypoglycaemia. The subjects complained of cramps in the legs, and in some instances suffered from incoherence and loss of steadiness. Complaints of headache and hunger were noted during the recovery period.

In accordance with the findings of Ahlborg (2) a correlation was found between the duration of work and the blood glucose content.

Furthermore, at the heavier work loads (more than 70 per cent of aerobic capacity), an increased blood sugar concentration was noted. Similar observations were obtained by Dill and colleagues (44) in a study of subjects that were exhausted by work of 10 to 40 minutes duration. These authors attributed this increase in blood glucose to mobilization of glycogen in both liver and muscle.

8. Tolerance times

The work tolerance curve illustrates that the level of work, and therefore oxygen consumption at which men could work for prolonged periods up to eight hours, was equal to 43 per cent of their aerobic capacities. Three of the four subjects could, however, maintain rates of work for that period at oxygen consumptions equivalent to 49-53 per cent of the maximum capacity. The mean curve indicates that at 50 per cent of the aerobic capacity, subjects in the present study could maintain the level of work for 432 minutes. This result thus confirms the findings of I. Åstrand (10) who demonstrated that both male and female subjects could work for seven hours at about 50 per cent of their respective aerobic capacities. The present study differs from that of Åstrand's in several important aspects. In the latter study test subjects worked for seven periods of 50 minutes with rest pauses of 10 minutes between work periods.

The third work period was followed by a lunch break of one hour instead of the 10 minute rest period. All subjects worked alternately on a bicycle ergometer and a treadmill. In the present study the men worked continuously for eight hours or for as long as they could tolerate the work on a bicycle ergometer. Agreement between the two studies are the subjective symptoms shown by both groups of test subjects on completion of a seven-hour work period, namely muscle fatigue, aching muscles and a feeling of severe hunger.

On the basis of these findings it can be concluded that the "50 per cent level" is not the recommended level of oxygen consumption for labourers working in heavy industry, mining, or other occupations where strenuous tasks are performed for long periods of either seven or eight hours daily.

Recently, Åstrand (11) tested the hypothesis of the "50 per cent load" which was originally made by Brody (26). In a study on a group of individuals occupied in the building industry, a definite correlation was found between the aerobic work capacity as measured in the laboratory and the occupational work load spontaneously chosen by the individual. The indications of the study were that a load of 40 per cent of aerobic capacity, rather then 50 per cent, as previously stated, would be a more reasonable limit for prolonged work.

With regard to the "optimum" level of energy expenditure at which labourers should work during an eight-hour shift, day after day and week after week, the present

results agree more closely with the findings of Michael and co-workers (89). These authors found that the energy cost of work should not exceed 35 per cent of the maximum oxygen intake of men if the task was to be tolerated without undue fatigue for a period of eight hours. In the present study the subjects could work at a level of oxygen consumption equivalent to 43 cent of their aerobic capacities without developing fatigue. Michael et al. established their figure of 35 per cent on three men running on a treadmill, but observed a significantly lower value for the same individuals when pedalling a bicycle ergometer. Attention should be drawn, however, to the fact that the subjects used in the present study were specially trained on a bicycle ergometer, while the men in the study by Michael et al. received limited training, consisting of two 25-minute periods daily on the ergometer and treadmill.

Müller (90) sets a limit on the basis of energy expenditure. He stated that men could work at an energy expenditure rate of 4 kcal per minute for hours without developing fatigue, which he called the "endurance limit". This will amount to about 2000 kcal for an eight-hour shift. He further indicated that if work were performed below the "endurance limit", pulse rate, after an initial increase to a steady state, would remain at a constant level proportional to the energy rate. Work above the "endurance limit" will result in a continuous increase of pulse rate during the course of the work period. Müller assumed that fatigue will develop sooner or later under such conditions.

Lehmann et al. (83) observed that "the maximum energetic output a normal man can afford in the long run, without any damage to his health or premature decrease of his strength, seems to be about 4,800 kcal per day". Lehmann calculated that 2,300 kcal are used for basal metabolism, leisure and personal activities, thus leaving 2,500 kcal for each working day. Of this, 500 kcal should be subtracted as a safety factor, the resultant amount of available energy for the working day being 2000 kcal. Müller (92), during 1962, compared Lehmann's criterion with the maximum capacity and observed that 2000 kcal per day corresponds to about 20 per cent of the maximum oxygen uptake for a man who is 20 to 30 years old.

Müller (92) is of the opinion that the individual's maximum capacity as an index of his capacity for prolonged work is unimportant. He feels that the increase in heart rate during work, the "Leistungs Pulse Index" is a more reliable index of the individual's "occupational work capacity". The Leistungs Pulse Index is the average increase in heart rate for 0.12 litre per minute increase in oxygen intake. He found that the L.P.I. does not increase with age, concluding that a man's capacity for endurance work will not decrease with ageing.

Passmore and Durnin (96) considered work at 5 kcal per minute as the upper limit at which an individual can work without an increase in the concentration of lactic acid in the blood. A similar hypothesis was postulated by Wyndham et al. (121), who defined the "optimum" level for energy expenditure as the highest level of oxygen consumption at

which no increase occurs in the concentration of "excess lactate" in the blood.

The present findings do not support these hypotheses. A logical conclusion to be drawn from the statement of Passmore and Durnin is that blood lactate concentrations start to increase when men work at from 25 to 33 per cent of their aerobic capacities. The present results indicated a level of 68 per cent of the aerobic capacity. These values, however, pertain to highly trained men; for untrained individuals it was previously found to be at 46 per cent (117). The finding in this study was that at a work load corresponding to 68 per cent of aerobic capacity, the point above which lactic acid accumulation occurs, the men's work tolerance was two hours.

The present study, in agreement with others, reported in the literature (53, 106) indicates that circulatory and respiratory changes are not limiting factors for prolonged exercise.

Different authors reported recently that the performance of prolonged work is limited by the available glycogen stores. Bergström and associates (24) found a good correlation between work time and the initial muscle glycogen content. It was shown by Ahlborg et al. (4) that endurance times were significantly longer after a carbohydrate rich diet compared to a mixed, normal diet or fat-protein diet, in a group of subjects that performed work at a relative load of about 70 per cent of aerobic capacity. Another important observation in the above study was that muscle glycogen is synthesized much more quickly after a diet

rich in carbohydrate than after a normal, mixed or fat-protein diet.

According to Ahlborg (3) the determination of muscle glycogen content by biopsy is a superior indication of a man's capacity for prolonged work.

9. Practical conclusions

The results of this study demonstrate that the "optimum" level of energy expenditure at which labourers should work during an eight hour shift, day after day and week after week, should not exceed about 40 per cent of their aerobic capacities. Heart rates during such work should not exceed 110 beats per minute after 15 minutes of work.

It is, however, realized that continuous work, such as was performed in this study, is rather unrealistic with regard to the work situation in the mines and heavy industry. The recuperation of individuals during rest periods may permit the performance of rates of work higher than specified for a normal eight-hour shift without manifestations of fatigue.

This information, however, could be useful in the selection of men who will be required to work very hard for limited periods, and also in situations where men work for shifts shorter than the usual eight hours.

REFERENCES

1. Adolph, E.F.
In: Physiology of man in the desert.
Interscience Publishers, Inc., New York, 1947.

2. Ahlborg, B.
Blood glucose during prolonged physical exercise in man.
Försvarsmedicin 3: 3-13, 1967.

3. Ahlborg, B.
Capacity for prolonged exercise in man.
Försvarsmedicin 3 (Suppl. 1) 1-35, 1967.

4. Ahlborg, B., J. Bergström, J. Brohult, L-G. Ekelund, E. Hultman and G. Maschio.
Human muscle glycogen content and capacity for prolonged exercise after different diets.
Försvarsmedicin 3: 85-99, 1967.

5. Ahlborg, B.J., J. Bergström, L-G. Ekelund and E. Hultman.
Muscle glycogen and muscle electrolytes during prolonged physical exercise.
Acta Physiol. Scand. 70: 129-142, 1967.

6. Asmussen, E.
Aerobic recovery after anaerobioses in rest and work.
Acta Physiol. Scand. 11: 197-210, 1946.

7. Asmussen, E.
Pyruvate and lactate content of the blood during and after muscular work.
Acta Physiol. Scand. 20: 125-132, 1950.

8. Asmussen, E. and I. Hemmingsen.
Determination of maximum working capacity at different ages in work with the legs or with the arms.
Scand. J. Clin. Lab. Invest. 10: 67-71, 1958.

9. Asmussen, E., W.v. Döbeln and M. Nielsen.
Blood lactate and oxygen debt after exhaustive work at different oxygen tensions.
Acta Physiol. Scand. 15: 57-62, 1948.

10. Åstrand, I.
Aerobic work capacity in men and women with special reference to age.
Acta Physiol. Scand. 49 (Suppl. 169): 1-92, 1960.

11. Åstrand, I.
Degree of strain during building work as related to individual aerobic work capacity.
Ergonomics 10: 292-303, 1967.

12. Åstrand, I., P.-O. Åstrand, E.H. Christensen and R. Hedman.
Circulatory and respiratory adaptation to severe muscular work.
Acta Physiol. Scand. 50: 254-258, 1960

13. Åstrand, I., P.-O. Åstrand and K. Rodahl.
Maximum heart rate during work in older men.
J. Appl. Physiol. 14: 562-566, 1959.

14. Åstrand, P.-O.
In: Experimental studies of physical working capacity in relation to sex and age.
Ejnar Munksgaard, Copenhagen, 1952.

15. Åstrand, P.-O., I. Hallbäck, R. Hedman and B. Saltin.
Blood lactates after prolonged severe exercise.
J. Appl. Physiol. 18: 619-622, 1963.

16. Åstrand, P.-O. and I. Ryhming.
A nomogram of calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work.
J. Appl. Physiol. 7: 218-221, 1954.

17. Åstrand, P.-O. and B. Saltin.
Oxygen uptake during the first minutes of heavy muscular exercise.
J. Appl. Physiol. 16: 971-976, 1961.

18. Åstrand, P.-O. and B. Saltin.
Maximal oxygen uptake and heart rate in various types of muscular activity.
J. Appl. Physiol. 16: 977-981, 1961.

19. Atkins, A.R. and J.D. Nicholson.
An accurate constant work rate ergometer.
J. Appl. Physiol. 18: 205-208, 1962.

20. Bang, O.
The lactate content of blood during and after muscular exercise in man.
Scand. Arch. Physiol. 74 (Suppl. 10): 49-82, 1936.

21. Barker, S.B. and W.H. Summerson.
The colorimetric determination of lactic acid in biological material.
J. Biol. Chem. 138: 535-554, 1941.

22. Barr, D.P. and H.E. Himwich.
Studies on the physiology of muscular exercise. II. Comparison of arterial and venous blood following vigorous exercise.
J. Biol. Chem. 55: 525-537, 1923.

23. Berggren, G. and E.H. Christensen.
Heart rate and body temperature as indices of metabolic rate during work.
Arbeitsphysiologie 14: 255-260, 1950.

24. Bergström, J., L. Hermansen, E. Hultman and B. Saltin.
Diet, muscle glycogen and physical performance.
Acta Physiol. Scand. 71: 140-150, 1967.

25. Binkhorst, R.A. and P. van Leeuwen.
A rapid method for the determination of aerobic capacity.
Intern. Z. Angew. Physiol. 19: 459-467, 1963.

26. Brody, S.
In: Bioenergetics and growth.
Reinhold Publishing Corporation, New York, 1945.

27. Bueding, E. and W. Goldfarb.
Blood changes following glucose, lactate and pyruvate injections in man.
J. Biol. Chem. 147: 33-40, 1943.

28. Bueding, E., M.H. Stein and H. Wortis.
The formation of pyruvic acid following glucose ingestion in man.
J. Biol. Chem. 137: 793-799, 1941.

29. Bueding, E., M.H. Stein and H. Wortis.
Blood pyruvate curves following glucose injection in normal and thiamin deficient subjects.
J. Biol. Chem. 140: 697-699, 1941.

30. Bueding, E. and H. Wortis.
The stabilization and determination of pyruvic acid in the blood.
J. Biol. Chem. 133: 585-591, 1940.

31. Bueding, E., H. Wortis and M. Stern.
Pathological variations in blood and spinal fluid pyruvic acid.
J. Clin. Invest. 21: 85-89, 1942.

32. Carlson, L.A. and B. Pernow.
Studies on the peripheral circulation and metabolism in man. I. Oxygen utilization and lactate-pyruvate formation in the legs at rest and during exercise in healthy cubjects.
Acta Physiol. Scand. 52: 328-342, 1961.

33. Carlson, L.A., B. Pernow and S. Zetterquist.
studies on the peripheral circulation and metabolism in man. III. Oxygen utilization and lactate-pyruvate formation in the legs at rest and during exercise in subjects with hyperkinetic circulation and low physical working capacity (vasoregulatory asthenia) and in healthy females.
Acta Med. Scand. 172: 389-400, 1962.

34. Christensen, E.H.
Beiträge zur Physiologie schwerer körperlicher Arbeit. IV. Die Pulsfrequenz während und mittelbar nach schwerer körperlicher Arbeit.
Arbeitsphysiologie 4: 453-469, 1931.

35. Christensen, E.H.
In: Physiological valuation of work in Nykroppa iron works.
Ergonomics Recearch Society Symposium on Fatique. Eds: W.F. Floyd and A.T. Welford.
H.K. Lewis and Co., Ltd., London, 1953, pp. 93-108.

36. Christensen, E.H.
Physical working capacity of old workers and physiological background for work evaluations.
Bull. World Health Organ. 13: 587-593, 1955.

37. Christensen, E.H. and O. Hansen.
Untersuchungen über die Verbrennungsvorgänge bei langdauernder, schwerer Muskelarbeit.
Skand. Arch. Physiol. 81: 152-159, 1939.

38. Christensen, E.H. and P. Högberg.
Physiology of skiing.
Arbeitsphysiologie 14: 292-303, 1950.

39. Cobb, L.A. and W.P. Johnson.
Hemodynamic relationships of anaerobic metabolism and plasma free fatty acids during prolonged, strenuous exercise in trained and untrained subjects.
J. Clin. Invest. 42: 800-810, 1963.

40. Cook, L.C. and R.H. Hurst.
Blood lactic acid in man during rest.
J. Physiol. 79: 443-454, 1933.

41. Davies, C.T.M. and E.A. Harris.
Heart rate during transition from rest to exercise, in relation to exercise tolerance.
J. Appl. Physiol. 19: 857-862, 1964.

42. Decker, D.G. and J.D. Rosenbaum.
The distribution of lactic acid in human blood.
Am. J. Physiol. 138: 7-11, 1942.

43. Dill, D.B., H.T. Edwards, P.S. Bauer and E.J. Levenson.
Physical performance in relation to external temperature.
Arbeitsphysiologie 4: 508-518, 1931.

44. Dill, D.B., H.T. Edwards and S. Mead.
Blood sugar regulation in exercise.
Am. J. Physiol. 11: 21-30, 1935.

45. Dill, D.B., J.H. Talbott and H.T. Edwards.
Studies in muscular activity. VI. Responses of several individuals to a fixed task.
J. Physiol. (London). 69: 267-305, 1930.

46. Donald, K.W., J.M. Bishop and O.L. Wade.
Changes in the oxygen content of axillary venous blood during leg exercise in patients with rheumatic heart disease.
Clin. Sci. 14: 531-551, 1955.

47. Donald, K.W., J. Gloster, E.A. Harris, J. Reeves and P. Harris.
The production of lactic acid during exercise in normal subjects and in patients with rheumatic heart disease.
Am. Heart. J. 62: 494-510, 1961.

48. Du Bois, D. and E.F. Du Bois.
A formula to estimate the approximate surface area if height and weight be known.
Arch. Internal. Med. 17: 863-871, 1916.

49. Duner, H.
Oxygen uptake and working capacity in man during work on the bicycle ergometer with one and both legs.
Acta Physiol. Scand. 46: 55-61, 1959.

50. Edwards, H.T., R. Margaria and D.B. Dill.
Metabolic rate, blood sugar and the utilization of carbohydrate.
Am. J. Physiol. 108: 203-209, 1934.

51. Eggleton, M.G. and C.L. Evans.
The lactic acid content of the blood after muscular contraction under experimental conditions.
J. Physiol. (London). 70: 269-293, 1930.

52. Ekelund, L.-G.
Circulatory and respiratory adaption during prolonged exercise.
Acta Physiol. Scand. 70 (Suppl. 292): 1-38, 1967.

53. Ekelund, L.-G. and A. Holmgren.
Circulatory and respiratory adaptation during long-term, non-steady state exercise, in the sitting position.
Acta Physiol. Scand. 62: 240-255, 1964.

54. Fenn, W.O., H. Rahn, A.B. Otis and L.E. Chadwick.
Physiological observations on hyperventilation at altitude with intermittent pressure breathing by pneumolator.
J. Appl. Physiol. 1: 773-789, 1948.

55. Fletcher, W.M., and F.G. Hopkins.
Lactic acid in amphibian muscle.
J. Physiol. (London). 35: 247-309, 1906-07.

56. Fox, E.L., S. Robinson, and D.L. Wiegman.
Metabolic energy sources during continuous and interval running.
J. Appl. Physiol. 27: 174-178, 1969.

57. Friedemann, T.E. and G.E. Haugen.
Pyruvic acid. II. The determination of keto acids in blood and urine.
J. Biol. Chem. 147: 415-442, 1943.

58. Friedemann, T.E., G.E. Haugen and T.C. Kmieciak. Pyruvic acid. III. The level of pyruvic and lactic acids, and the lactic-pyruvic ratio, in the blood of human subjects. The effect of food, light muscular activity and anoxia at high altitude. J. Biol. Chem. 157: 673-689, 1945.

59. Goldsmith, G.A. The blood lactate-pyruvate relationship in various physiologic and pathologic states. Am. J. Med. Sci. 215: 182-188, 1948.

60. Griffith, F.R., A. Omachi, J.E. Lockwood and T.A. Loomis. The effect of intravenous adrenalin on blood flow, sugar retention, lactate output and respiratory metabolism of peripheral (leg) tissues in the anaesthetized cat. Am. J. Physiol. 149: 64-76, 1947.

61. Grimby, G. Exercise in man during pyrogen induced fever. Scand. J. Clin. Lab. Invest. 14 (Suppl. 67): 5-112, 1962.

62. Harris, P., M. Bateman and J. Gloster. Relations between the cardio-respiratory effects of exercise and the arterial concentration of lactate and pyruvate in patients with rheumatic heart disease. Clin. Sci. 23: 531-543, 1962.

63. Havel, R.J., L.A. Carlson, L.-G. Ekelund and A. Holmgren. Turnover rate and oxidation of different free fatty acids in man during exercise. J. Appl. Physiol. 19: 613-618, 1964.

64. Hill, A.V., C.N.H. Long and H. Lupton. Muscular exercise, lactic acid and the supply and utilization of oxygen. VII. Muscular exercise and oxygen intake. Proc. Roy. Soc. (London), Ser. B. 97: 155-167, 1924.

65. Hill, A.V., C.N.H. Long and H. Lupton. Muscular exercise, lactic acid and the supply and utilization of oxygen. I. Introduction. Proc. Roy. Soc. (London), Ser. B. 96: 438-443, 1924.

66. Hill, A.V. and H. Lupton.
Muscular exercise, lactic acid and the supply and utilization of oxygen.
Quart. J. Med. 16: 135-171, 1923.

67. Holmgren, A.
Arterio-venous lactic acid differences in man at rest and during muscular work.
Scand. J. Clin. Lab. Invest. 11: 150-153, 1959.

68. Holmgren, A. and B. Pernow.
The reproducibility of cardiac output determination by the direct Fick method during muscular work.
Scand. J. Clin. Lab. Invest. 12: 224-227, 1960.

69. Holmgren, A. and G. Ström.
Blood lactate concentration in relation to absolute and relative work load in normal men, and in mitral stenosis, arterial septel defect and vasoregulatory asthenia.
Acta Med. Scand. 163: 185-193, 1959.

70. Hood, W.B., N. Krasnow, E.L. Rolett, P.M. Yurchak and R. Gorlin.
Anaerobic metabolism of the exercising leg in man.
Clin. Sci. 28: 175-189, 1965.

71. Huckabee, W.E.
Control of concentration gradients of pyruvate and lactate across cell membranes in blood.
J. Appl. Physiol. 9: 163-170, 1956.

72. Huckabee, W.E.
Relationships of pyruvate and lactate during anaerobic metabolism. I. Effects of infusion of pyruvate or glucose and of hyperventilation.
J. Clin. Invest. 37: 244-254, 1958.

73. Huckabee, W.E.
Relationships of pyruvate and lactate during anaerobic metabolism. II. Exercise and formation of O_2- debt.
J. Clin. Invest. 37: 255-263, 1958.

74. Hullin, R.P. and R.L. Noble.
The determination of lactic acid in microgram quantities.
Biochem. J. 55: 289-291, 1953.

75. Hultman, E.
Rapid specific method for determination of aldosaccharides in body fluids.
Nature 183: 108-109, 1959.

76. Hyvärinen, A. and E.A. Nikkilä.
Specific determination of blood glucose with o-toluidine.
Clin. Chim. Acta 7: 140-143, 1962.

77. Issekutz, B., N.C. Birkhead and K. Rodahl.
Use of respiratory quotients in assessment of aerobic work capacity.
J. Appl. Physiol. 17: 47-50, 1962.

78. Jervell, O.
Investigations of the concentration of lactic acid in the blood and urine under physiologic and pathologic conditions.
Acta Med. Scand. (Suppl. 24): 1-135, 1928.

79. Karlsson, J., B. Diamant and B. Saltin.
Lactate dehydrogenase activitly in muscle after prolonged severe exercise in man.
J. Appl. Physiol. 25: 88-91, 1968.

80. Knehr, C.A., D.B. Dill and W. Neufeld.
Training and its effects on man at rest and at work.
Am. J. Physiol. 148: 136-155, 1942.

81. Knuttgen, H.G.
Oxygen debt, lactate, pyruvate and excess lactate after muscular work.
J. Appl. Physiol. 17: 639-644, 1962.

82. Krogh, A. and J. Lindhard.
The relative value of fat and carbohydrate as sources of muscular energy.
Biochem. J. 14: 290-363, 1920.

83. Lehmann, G., E.A. Müller and H. Spitzer.
Der Kalorienbedarf bei gewerblicher Arbeit.
Arbeitsphysiologie 14: 166-235, 1950.

84. Lukin, L. and H.J. Ralston.
Oxygen deficit and repayment in exercise.
Intern. Z. Angew. Physiol. 19: 183-193, 1962.

85. Margaria, R., P. Aghemo and E. Rovelli.
Indirect determination of maximal oxygen consumption in man.
J. Appl. Physiol. 20: 1070-1073, 1965.

86. Margaria, R., P. Cerretelli, P.E. Diprampero, C. Massari and G. Torelli.
Kinetics and mechanism of oxygen debt contraction in man.
J. Appl. Physiol. 18: 371-377, 1963.

87. Margaria, R., H.T. Edwards and D.B. Dill.
The possible mechanisms of contracting and paying the oxygen debt and the role of lactic acid in muscular contraction.
Am. J. Physiol. 106: 689-715, 1933.

88. Maritz, J.S., J.F. Morrison, J. Peter, N.B. Strydom and C.H. Wyndham.
A practical method of estimating an individual's maximal oxygen intake.
Ergonomics 4: 97-122, 1961.

89. Michael, E.D., K.E. Hutton and S.M. Horvath.
Cardiorespiratory responses during prolonged exercise.
J. Appl. Physiol. 16: 997-1000, 1961.

90. Müller, E.A.
The physiological basis of rest pauses in heavy work.
Quart, J. Exp. Physiol. 38: 205-215, 1953.

91. Müller, E.A.
Die ärztliche Beurteilung der körperlichen Dauer-Leistungsfähigkeit im Beruf.
Deut. Med. Wochschr. 86: 2272-2277, 1961.

92. Müller, E.A.
Occupational work capacity and maximum work capacity.
Ergonomics 5: 445-451, 1962.

93. Newman, E.V., D.B. Dill, H.T. Edwards and F.A. Webster.
The rate of lactic acid removal in exercise.
Am. J. Physiol. 118: 457-462, 1937.

94. Nielsen, M.
Die Regulation der Körpertemperatur bei Muskalarbeit.
Scand. Arch. Physiol. 79: 193-230, 1938.

95. Owles, W.H.
Alterations in the lactic acid content of the blood as a result of light exercise and associated changes in the CO_2-combining power of the blood and in the alveolar CO_2-pressure.
J. Physiol. (London). 69: 214-237, 1930.

96. Passmore, R. and J.V.G.A. Durnin.
Human energy expenditure.
Physiol. Rev. 35: 801-840, 1955.

97. Pauling, L., R.E. Wood and J.H. Sturdivant.
An instrument for determining the partial pressure of oxygen in a gas.
J. Am. Chem. Soc. 68: 795-798, 1964.

98. Pernow, B. and J. Wahren.
Lactate and pyruvate formation and oxygen utilization in the human forearm muscles during work of high intensity and varying duration.
Acta Physiol. Scand. 56: 267-285, 1962.

99. Platt, B.S. and G.D. Lu.
Studies on the metabolism of pyruvic acid in normal and vitamin B_1-deficient states.
IV. The accumulation of pyruvic acid and other carbonyl compounds in beri-beri and the effect of vitamin B_1.
Biochem. J. 33: 1525-1537, 1939.

100. Rakestraw, N.W.I.
Chemical factors in fatique. The effect of muscular exercise upon common blood constituents.
J. Biol. Chem. 47: 565-591, 1921.

101. Robinson, S.
Adaption of White men and Negroes to prolonged work in humid heat.
Am. J. Physiol. 21: 261-270, 1941.

102. Robinson, S., H.T. Edwards and D.B. Dill.
New records in human power.
Science 85: 409-410, 1937.

103. Robinson, S. and P.M. Harmon.
The lactic acid mechanism and certain properties of the blood in relation to training.
Am. J. Physiol. 132: 757-769, 1941.

104. Robinson, S. and P.M. Harmon.
The effect of training and gelatin upon certain factors which limit muscular work.
Am. J. Physiol. 133: 161-169, 1941.

105. Rodahl, K., H.I. Miller and B. Issekutz.
Plasma free fatty acids in exercise.
J. Appl. Physiol. 19: 489-492, 1964.

106. Saltin, B. and J. Stenberg.
Circulatory response to prolonged severe exercise.
J. Appl. Physiol. 19: 833-838, 1964.

107. Strandell, B.
On the influence of exercise on the blood sugar, expecially in connection with glucose ingestion.
Acta Med. Scand. (Suppl. 55) 1934.

108. Strydom, N.B., H.M. Cooke, H.D. Millar and P. Winer.
Errors in respiratory gas analysis. A comparison of the Haldane and Pauling gas analyzers.
Intern. Z. Angew. Physiol. 21: 13-26, 1965.

109. Ström, G.
The influence of anoxia on lactate utilization in man after prolonged muscular work.
Acta Physiol. Scand. 17: 440-451, 1949.

110. Taylor, C.L.
Some properties of maximal and submaximal exercise with reference to physiological variation and the measurement of exercise tolerance.
Am. J. Physiol. 142; 200-212, 1944.

111. Taylor, H.L., E. Bushkirk and A. Henschel.
Maximal oxygen intake as an objective measure of cardio-respiratory performance.
J. Appl. Physiol. 8: 73-80, 1955.

112. Taylor, H.L., A Henschel, A. Brozek and A. Keys.
Effects of bed rest on cardiovascular function and work performance.
J. Appl. Physiol. 2: 223-239, 1949.

113. Thomas, H.D., B. Boshell, C. Gaos and T.J. Reeves.
Cardiac output during exercise and anaerobic metabolism in man.
J. Appl. Physiol. 19: 839-848, 1964.

114. Wells, J.G., B. Blake and D.D. van Fossan.
Lactic acid accumulation during work. A suggested standardization of work classification.
J. Appl. Physiol. 10: 51-55, 1957.

115. Williams, C.G., G.A.G. Bredell, C.H. Wyndham, N.B. Strydom, J.F. Morrison, J. Peter, P.W. Fleming and J.S. Ward.
Circulatory and metabolic reactions to work in heat.
J. Appl. Physiol. 17: 625-638, 1962.

116. Williams, C.G., A.J.N. du Raan, M.J. von Rahden and C.H. Wyndham.
The capacity for endurance work in highly trained men.
Intern. Z. Angew. Physiol. 26: 141-149, 1968.

117. Williams, C.G., C.H. Wyndham, R. Kok and M.J. von Rahden.
Effect of training on maximum oxygen intake and on anaerobic metabolism.
Intern. Z. Angew. Physiol. 24: 18-23, 1967.

118. Wyndham, C.H., H.C. Seftel, C.G. Williams, V. Wilson, N.B. Strydom, G.A.G. Bredell and M.J.E. von Rahden.
Circulatory mechanisms of anaerobic metabolism in working muscle.
S. African Med. J. 39: 1008-1014, 1965.

119. Wyndham, C.H., N.B. Strydom, J.S. Maritz, J.F. Morrison, J. Peter and Z.U. Potgieter. Maximum oxygen intake and maximum heart rate during strenuous work. J. Appl. Physiol. 14: 927-936, 1959.

120. Wyndham, C.H., N.B. Strydom, C.G. Williams, G.A.G. Bredell, J.S. Maritz and A. Munroe. Criteria for physiological limits for work in heat. J. Appl. Physiol. 20: 37-45, 1965.

121. Wyndham, C.G., N.B. Strydom, C.G. Williams, and M.J. von Rahden. A physiological basis for the "optimum" level of energy expenditure. Nature 195: 1210-1212, 1962.

122. Young, D.R., R. Pelligra and R.R. Adachi. Serum glucose and free fatty acids in man during prolonged exercise. J. Appl. Physiol. 21: 1047-1052, 1966.

TABLE III SUBJECT: DA AVERAGE VALUES

END TIME	WORK RATE	x	TIME	HEART RATE	RECTAL TEMP.	OXYGEN INTAKE	mM PA	mM LA	mM XL	GLUCOSE
			9	101		1.30	0.119	0.889	-0.043	
			15	95	97.5					
			60	95	98.8					
			120	98	99.4	1.23	0.090	0.662	-0.066	69.7
			180	97	99.5					
480+	5000	3	240	97	99.5	1.39	0.094	0.673	-0.050	63.9
			300	93	99.5					
			360	104	99.7	1.43	0.095	0.690	-0.032	60.1
			420	107	99.6					
			480	111	99.8	1.45	0.136	0.882	-0.161	51.5
			15	111	97.7					
			60	104	99.8					
			120	106	99.6	1.57	0.094	0.801	0.119	71.7
			180	110	100.0					
480	6000	3	240	117	99.8	1.60	0.109	0.812	0.015	63.1
			300	117	99.7					
			360	118	99.4	1.66	0.132	0.817	-0.133	62.2
			420	116	99.2					
			480	120	99.3	1.67	0.137	1.041	0.328	53.4
			15	107	98.3					
			60	104	99.7					
			120	110	99.8	1.74	0.116	0.811	-0.186	68.0
337	6500	3	180	110	99.4					
			240	120	99.8	1.73	0.092	0.714	-0.073	65.5
			300	120	99.2					
			T	124	99.2	1.78	0.091	0.800	0.010	63.9
			9	118		1.73	0.117	0.860	-0.025	
			15	109	97.8					
			60	115	100.2					
265	7000	3	120	119	100.6	1.82	0.100	0.869	0.202	73.8
			180	119	100.1					
			240	128	100.0	1.89	0.101	0.908	-0.117	71.2
			T	131	99.9	1.91	0.115	0.937	-0.110	64.0
			15	126	97.8					
125	8000	3	60	130	100.0					
			T	131	100.3	2.13	0.134	1.166	0.139	71.6
			9	135		2.17	0.167	1.731	0.467	
			15	134	97.6					
77	9000	3	60	143	100.3					
			T	147	100.0	2.36	0.199	1.951	0.333	68.1
			15	152	99.4					
34	10000	3	T	160	100.4	2.56	0.281	4.534	2.205	74.2
			15	159	98.3					
28	10500	3	T	165	100.1	2.83	0.280	6.239	3.704	75.5
			15	171	98.8					
21	11000	5	T	175	99.6	2.90	0.324	0.224	6.525	79.3
5	12000	3	T	167		3.07	0.252	8.338	6.132	
4½	13000	3	T	172		3.19	0.306	8.800	6.115	
2½	14000	3	T	169		3.09				
2	15000	3	T	169		3.04				

X Number of repeat experiments.
T Terminal value.

TABLE IV SUBJECT: FR AVERAGE VALUES.

END TIME	WORK RATE	x	TIME	HEART RATE	RECTAL TEMP.	OXYGEN INTAKE	ml PA	ml LA	ml XL	GLUCOSE
			9	100		0.92	0.219	1.901	-0.118	
			15	97	97.5					
			60	97	98.8					
			120	108	99.3	0.87	0.115	0.865	-0.085	71.1
			180	101	99.3					
480+	3000	3	240	107	99.4	0.91	0.104	0.652	-0.042	66.7
			300	108	99.1					
			360	110	99.5	0.97	0.130	0.656	-0.438	61.3
			420	112	99.3					
			480	119	99.5	1.04	0.133	0.841	-0.277	58.1
			9	109		1.16	0.127	1.102	0.074	
			15	118	97.6					
			60	121	99.2					
			120	124	99.7	1.33	0.130	0.901	-0.221	70.6
			180	125	100.0					
480	4000	3	240	134	100.1	1.30	0.137	0.843	-0.313	60.4
			300	132	100.1					
			360	139	100.1	1.32	0.143	0.937	-0.291	60.5
			420	137	99.6					
			480	145	100.3	1.40	0.181	1.087	-0.482	53.7
			15	130	98.7					
			60	131	99.9					
			120	137	100.2	1.42	0.103	0.835	-0.085	66.7
320	4500	3	180	139	99.8					
			240	147	99.9	1.48	0.172	1.178	-0.310	54.3
			300	145	99.9					
			T	144	100.6	1.50	0.176	1.219	-0.350	51.2
			9	122		1.43	0.145	1.352	0.184	
			15	139	98.7					
			60	142	100.0					
240	5000	3	120	144	99.3	1.60	0.145	1.213	-0.341	61.9
			180	153	100.2					
			T	161	101.0	1.71	0.203	1.808	0.614	52.0
			9	134		1.68	0.175	1.826	0.455	
			15	142	99.8					
133	6000	3	80	146	100.3					
			120	152	100.6	1.89	0.147	1.243	-0.070	64.1
			T	158	100.2	2.03	0.121	1.090	-0.155	58.1
			9	156		1.93	0.224	3.106	0.371	
			15	154	98.0					
83	7000	3	60	159	100.4					
			T	170	100.5	2.12	0.261	4.247	1.646	67.6
			9	167		2.24	0.289	5.083	2.728	
			15	162	98.4					
58	8500	3	T	160	101.0	2.22	0.342	7.241	3.449	77.3
			9	181		2.69	0.333	9.185	6.470	
			15	173	99.0					
25	9000	3	T	177	100.0	2.57	0.337	10.647	7.168	67.5
5	10000	3	T	180		2.82				
3½	11000	3	T	183		3.03				
2	12000	3	T	183		3.02				
1½	13000	2	T	182		3.07				

X Number of repeat experiments.
T Terminal value.

TABLE V — SUBJECT: MA — AVERAGE VALUES.

END TIME	WORK RATE	x	TIME	HEART RATE	RECTAL TEMP.	OXYGEN INTAKE	mM PA	mM LA	mM XL	GLUCOSE
			9	107		1.46	0.099	0.807	0.807	
			15	102	97.9					
			60	103	99.1					
			120	104	99.6	1.41	0.118	0.928	-0.014	67.3
			180	102	99.1					
480+	5000	3	240	104	99.5	1.48	0.096	0.760	0.005	63.3
			300	102	99.3					
			360	105	99.6	1.57	0.107	0.738	-0.113	59.1
			420	108	99.7					
			480	109	99.8	1.63	0.127	0.773	-0.254	59.1
			15	109	98.6					
			60	110	99.9					
			120	107	99.9	1.55	0.084	0.689	0.012	71.8
			180	110	99.8					
480	6000	3	240	114	100.1	1.82	0.114	0.645	-0.266	65.9
			300	117	100.1					
			360	117	100.3	1.76	0.111	0.742	-0.156	59.9
			420	124	100.6					
			480	123	100.3	1.82	0.136	1.003	-0.080	56.1
			15	108	98.3					
			60	109	100.1					
			120	111	99.9	1.85	0.127	0.964	-0.155	67.0
386	6500	3	180	110	99.9					
			240	113	99.9	1.87	0.102	0.680	0.114	62.3
			300	114	99.8					
			360	113	99.8	1.87	0.109	0.935	0.132	56.8
			T	116	100.0	1.95	0.123	0.863	0.052	54.8
			9	120		2.00	0.157	1.050	-0.080	
			15	115	98.4					
			60	117	100.0					
			120	120	100.4	1.90	0.103	0.757	0.043	71.0
322	7000	3	180	120	100.4					
			240	126	100.6	1.95	0.086	0.802	0.195	58.0
			360	132	100.6					
			T	138	100.8	2.00	0.109	0.869	-0.020	55.3
			15	120	98.6					
			60	130	99.6					
212	8000	3	120	135	99.7	2.28	0.089	0.789	0.061	61.8
			180	132	99.7					
			T	133	99.8	2.28	0.106	0.982	0.117	57.5
			9	135		2.47	0.134	1.255	0.143	
			15	133	98.7					
109	9000	3	60	137	101.0					
			T	140	101.2	2.51	0.140	1.209	0.159	69.0
50	10000	3	15	139	98.6					
			T	151	100.6	2.75	0.171	2.531	1.837	82.4
			9	153		3.06	0.188	3.737	2.139	
36	11000	3	15	149	99.1					
			T	158	101.6	3.08	0.241	3.868	1.761	83.0
17	12000	3	T	153	99.6	3.26	0.329	6.481	3.753	70.4
5	13000	5	T	161		3.57	0.318	8.365	5.981	
4	14000	3	T	166		3.75	0.445	10.179	4.727	
3	15000	5	T	168		3.74	0.296	8.792	6.723	
2½	16000	3	T	168		3.75				

X Number of repeat experiments.

T Terminal value.

TABLE VI — SUBJECT: ZE — AVERAGE VALUES.

END TIME	WORK RATE	x	TIME	HEART RATE	RECTAL TEMP.	OXYGEN INTAKE	mM PA	mM LA	mM XL	GLUCOSE
			9	99		1.08	0.156	1.162	0.025	
			15	93	98.0					
			60	93	99.0					
			120	94	99.2	1.08	0.193	1.134	-0.254	59.9
			180	97	99.3					
480+	4000	3	240	97	99.4	1.06	0.152	0.904	-0.198	61.8
			300	100	99.3					
			360	99	99.6	1.10	0.130	0.818	-0.134	58.8
			420	104	99.7					
			480	105	99.7	1.20	0.177	0.972	-0.252	56.9
			9	109		1.34	0.151	1.133	0.044	
			15	108	98.5					
			60	109	99.6					
			120	109	100.0	1.32	0.161	1.120	-0.002	63.7
			180	116	100.0					
480	5000	3	240	117	100.1	1.42	0.161	1.075	-0.016	56.8
			300	121	100.2					
			360	122	100.1	1.45	0.157	1.003	-0.111	51.1
			420	124	100.1					
			480	128	100.2	1.44	0.188	1.304	-0.013	44.0
			15	108	98.5					
			60	110	99.7					
			120	114	100.0	1.49	0.143	1.129	-0.169	62.4
360	5500	3	180	123	100.4					
			240	130	100.1	1.53	0.135	1.118	0.076	58.8
			300	137	100.2					
			360	138	100.3	1.61	0.171	1.136	-0.421	52.1
			T	135	100.6	1.55	0.163	1.242	0.000	52.2
			9	119		1.59	0.176	1.419	0.157	
			15	124	98.6					
			60	127	100.1					
			120	135	100.4	1.82	0.206	1.618	-0.029	60.5
295	6000	3	180	141	100.4					
			240	149	100.5	1.93	0.245	1.922	0.085	52.2
			T	141	100.3	1.73	1.140	1.186	-0.041	48.9
			9	135		1.97	0.252	2.252	0.350	
			15	133	99.0					
			60	145	100.5					
132	7000	3	120	156	100.9	2.02	0.272	2.790	0.512	55.6
			T	162	101.4	2.04	0.198	1.934	0.311	61.4
			9	153		2.25	0.274	3.125	0.914	
			15	147	98.9					
97	8000	3	60	167	101.0					
			T	174	101.8	2.29	0.293	4.296	2.183	59.3
			15	149	98.9					
56	8500	3	T	160	100.6	2.39	0.294	5.593	2.994	61.7
			9	166		2.55	0.395	7.655	4.187	
			15	167	99.4					
29	9000	3	T	172	100.5	2.50	0.448	12.095	7.765	71.6
4½	10000	4	T	172		2.80	0.395	10.109	6.872	
3½	11000	2	T	174		2.65				
2	12000	4	T	174		2.72				

X Number of repeat experiments.

T Terminal value.

TABLE VII

GROUPED DATA - HEART RATE (Beats per minute)

x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	9	15	60	120	180	240	300	360	420	480
RELATIVE WORK LOAD ÷ = 40% of Max. Cap.	MA.	5000	480+	108	106	102	106	109	109	106	111	119	118
			480+	105	102	102	-	96	94	98	99	101	108
			480+	109	100	105	102	102	109	102	104	103	100
	DA.	5000	480+	106	98	94	102	100	109	102	106	110	110
			480+	98	96	103	102	102	104	103	110	115	119
			480+	97	93	89	91	90	96	90	97	96	105
	ZE.	4000	480+	95	97	96	97	102	102	106	113	111	111
			480+	101	86	89	95	97	94	102	102	106	109
			480+	102	96	-	91	93	94	92	82	96	96
RELATIVE WORK LOAD ÷ = 50% of Max. Cap.	MA.	6500	401	-	104	105	111	102	109	118	109	112x	
			395	-	107	112	110	114	109	-	119	120x	
			361	-	112	111	-	114	120	109	111x		
	DA.	6000	480	-	119	110	114	117	125	126	127	123	124x
			480	-	103	101	102	110	116	115	117	114	125
			480	-	110	102	101	102	109	110	110	112	110
	ZE.	5000	480	102	110	106	111	118	121	126	126	129	132
			480	112	110	116	114	120	122	123	130	129	132
			480	113	104	104	103	109	109	113	111	113	119
RELATIVE WORK LOAD ÷ = 55% of Max. Cap.	MA.	7000	339	118	114	115	122	122	128	130	142x		
			295	117	114	118	117	118	122	135x			
			332	124	116	118	121	121	127	130	134x		
	DA.	6500	333	-	107	102	105	109	120	121	126x		
			347	-	105	104	106	111	120	118	121x		
			324	-	109	106	118	110	121	121	130x		
	ZE.	5500	437	-	106	112	111	122	128	130	130	134	136x
			336	-	105	109	115	124	134	148	145x		
			336	-	116	109	117	124	135	134	140x		
RELATIVE WORK LOAD ÷ = 60% of Max. Cap.	MA.	8000	201	-	126	132	131	132	136x				
			190	-	117	131	134	-	132x				
			244	-	118	127	139	131	131x				
	DA.	7000	240	118	107	117	127	123	126				
			284	120	111	111	111	118	128	127x			
			270	115	109	116	118	117	131	135x			
	ZE.	6000	332	114	122	121	127	134	135	140	145x		
			301	120	118	123	125	134	136	139x			
			246	124	132	137	153	177x					

	SUBJECT	WORK RATE	ENDURANCE TIME	9	15	60	120	180
RELATIVE WORK LOAD ÷ = 70% of Max. Cap.	MA.	9000	120	136	135	138	146	
			120	135	126	136	134	
			87	134	138	138	140x	
	DA.	8000	125	-	131	138	132x	
			121	-	124	128	133x	
			122	-	124	124	127x	
	ZE.	7000	120	135	143	163	171	
			135	134	128	144	138	162x
			120	145	129	129	138	
RELATIVE WORK LOAD ÷ = 80% of Max. Cap.	MA.	11000	40	156	152	154x		
			36	161	145	162x		
			32	141	151	158x		
	DA.	10000	33	-	158	167x		
			35	-	137	148x		
			34	-	163	166x		
	ZE.	8500	52	-	150	160x		
			57	-	146	152x		
			58	-	150	168x		
RELATIVE WORK LOAD ÷ = 90% of Max. Cap.	MA.	12000	16	-	-	154x		
			18	-	-	156x		
			17	-	-	150x		
	DA.	10500	28	-	159	167x		
			27	-	160	162x		
			28	-	157	165x		
	ZE.	9000	30	107	162	170x		
			28	172	170	174x		
			29	163	168	172x		
RELATIVE WORK LOAD ÷ = 100% of Max. Cap.	MA.	14000	4	167x				
			4	168x				
			4	163x				
	DA.	13000	5	172x				
			4.5	173x				
			4.5	170x				
	ZE.	10000	4.5	174x				
			4.5	178x				
			4.5	170x				

TABLE VIII

GROUPED DATA - OXYGEN INTAKE (Litres per minute)

x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240	360	480
RELATIVE WORK LOAD ± 40% OF MAX. CAPACITY	MA.	5000	480+	1.55	1.38	1.47	1.57	1.62
			480+	1.39	1.11	1.50	1.60	1.76
			480+	1.44	1.72	1.46	1.53	1.50
	DA.	5000	480+	1.44	1.28	1.36	1.44	1.43
			480+	1.20	1.36	1.44	1.51	1.51
			480+	1.25	1.20	1.36	1.33	1.41
	ZE.	4000	480+	1.07	1.12	1.16	1.15	1.17
			480+	1.08	1.03	1.06	1.15	1.04
			480+	1.09	1.08	0.97	1.01	1.15
RELATIVE WORK LOAD ± 50% OF MAX. CAPACITY	MA.	6500	481	-	1.85	1.88	1.84	1.93x
			359	-	1.81	1.85	1.88	1.96x
			361	-	1.98	1.88	1.98x	
	DA.	6000	480	-	-	-	-	1.71
			480	-	1.52	1.53	1.65	1.63
			480	-	1.62	1.67	1.67	1.66
	ZE.	5000	480	1.32	1.32	1.46	-	1.45
			480	1.37	1.40	1.50	1.50	1.49
			480	1.34	1.25	1.30	1.40	1.37
RELATIVE WORK LOAD ± 55% OF MAX. CAPACITY	MA.	7000	339	2.04	1.96	1.99	2.06x	
			295	1.98	1.89	1.79	1.88x	
			332	1.98	1.86	2.07	2.07x	
	DA.	6500	333	-	-	1.77	1.83x	
			347	-	1.74	1.88	1.68x	
			324	-	1.73	1.62	1.84x	
	ZE.	8500	437	-	1.45	1.57	1.61	1.55x
			336	-	1.52	1.66	1.66x	
			336	-	1.49	1.35	1.55x	
RELATIVE WORK LOAD ± 60% OF MAX. CAPACITY	MA.	8000	201	-	2.22	2.22x		
			190	-	2.42	2.26x		
			244	-	2.21	2.36x		
	DA.	7000	240	1.84	1.84	1.89		
			284	1.67	1.77	1.91	1.96x	
			270	1.67	1.84	1.87	1.86x	
	ZE.	6000	332	1.59	1.73	1.68	1.77x	
			301	1.62	1.74	2.10	1.68x	
			246	1.57	1.98	2.07x		

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	360
RELATIVE WORK LOAD + 70% OF MAX. CAPACITY	MA.	9000	120	2.35	2.63	
			120	2.48	2.55	
			87	2.39	2.36x	
	DA.	8000	125	-	2.15x	
			121	-	2.11x	
			122	-	2.12x	
	ZE.	7000	120	2.05	2.08	
			135	1.93	2.04	2.04x
			120	1.96	1.95	
RELATIVE WORK LOAD +1 80% OF MAX. CAPACITY	MA.	11000	40	2.96	-	
			36	3.29	2.97x	
			32	2.94	3.19x	
	DA.	10000	33	-	2.64x	
			35	-	2.36x	
			34	-	2.69x	
	ZE.	8500	52	-	2.36x	
			57	-	2.36x	
			58	-	2.46x	
RELATIVE WORK LOAD + 90% OF MAX. CAPACITY	MA.	12000	16	-	3.16x	
			18	-	3.29x	
			17	-	3.34x	
	DA.	10500	28	-	2.88x	
			27	-	2.76x	
			28	-	2.85x	
	ZE.	9000	30	2.61	2.49x	
			28	2.51	2.49x	
			29	2.52	2.52x	
RELATIVE WORK LOAD ±100% OF MAX. CAPACITY	MA.	14000	4	3.77x		
			4	3.81x		
			4	3.68x		
	DA.	13000	5	3.08x		
			4.5	3.23x		
			4.5	3.03x		
	ZE.	10000	4.5	2.66x		
			4.5	2.91x		
			4.5	2.90x		

	SUBJECT	WORK RATE	ENDURANCE TIME	15	60	120	180	240	300	360	420	480
RELATIVE WORK LOAD ÷ = 40% of Max. Cap.	MA.	5000	480+	98.5	99.8	99.6	99.6	99.8	99.8	99.9	99.8	100.0
			480+	98.1	99.7	99.6	-	99.3	99.4	99.3	99.6	99.6
			480+	97.2	97.8	99.6	98.6	99.4	98.8	99.5	99.8	99.9
	DA.	5000	480+	97.6	-	99.2	99.1	99.4	99.5	99.5	99.8	99.8
			480+	97.3	98.4	99.4	99.4	99.4	99.4	99.8	99.7	99.7
			480+	97.5	99.2	99.5	99.9	99.6	-	99.8	99.5	99.8
	ZE.	4000	480+	98.0	99.2	99.5	99.3	99.7	99.4	99.7	99.7	99.7
			480+	98.0	98.9	99.2	99.4	99.5	99.6	99.9	100.1	100.0
			480+	97.9	98.9	99.0	99.1	98.9	98.8	99.1	99.4	99.4
RELATIVE WORK LOAD ÷ = 50% of Max. Cap.	MA.	6500	491	98.2	100.0	100.0	99.9	100.0	100.0	99.8	99.6x	
			395	98.3	100.3	100.3	99.9	99.7	-	100.3	100.3x	
			361	98.5	99.9	99.4	99.9	100.0	99.6	99.4x		
	DA.	6000	480	98.3	99.7	99.2	100.1	-	-	-	-	-
			480	96.9	-	99.8	99.7	99.8	99.3	99.1	98.8	99.3
			480	98.0	99.8	99.9	100.1	99.8	100.1	99.7	99.5	99.3
	ZE.	5000	480	98.3	99.6	99.9	100.1	100.2	100.3	100.2	100.0	100.3
			480	98.8	99.8	100.1	-	100.1	-	100.1	100.1	100.0
			480	98.3	99.5	99.9	99.9	100.0	100.0	100.0	100.1	100.2
RELATIVE WORK LOAD ÷ = 55% of Max. Cap.	MA.	7000	339	98.1	99.8	100.4	100.7	100.8	100.8	100.9x		
			295	98.8	100.3	100.4	100.4	100.5	100.8x			
			332	98.4	100.0	100.4	100.2	100.6	100.3	100.7x		
	DA.	6500	333	98.0	100.1	100.3	-	100.3	-	99.9x		
			347	98.4	99.2	99.4	99.3	-	-	98.5x		
			324	98.4	99.2	99.6	99.4	99.3	99.2	99.2x		
	ZE.	5500	437	98.8	99.9	100.2	100.2	100.3	100.6	100.3	100.6	100.5x
			336	97.9	99.5	99.6	-	99.6	100.0	100.1x		
			336	98.7	99.8	100.2	100.5	100.3	100.0	100.4x		
RELATIVE WORK LOAD ÷ = 60% of Max. Cap.	MA.	8000	201	98.1	100.4	100.8	100.8	101.0x				
			190	99.6	100.3	100.3	-	98.5x				
			244	98.1	98.1	98.1	98.6	100.0x				
	DA.	7000	240	97.6	100.3	100.5	100.2	100.2				
			284	97.5	-	100.1	100.1	100.0	99.9x			
			270	98.3	100.1	101.2	99.9	99.8	99.8x			
	ZE.	6000	332	98.8	100.0	100.2	100.1	100.1	100.2	100.5x		
			301	97.6	99.7	100.2	100.2	100.1	100.1x			
			246	99.5	100.7	100.9	101.0	101.2x				

	SUBJECT	WORK RATE	ENDURANCE TIME	15	60	120	180
RELATIVE WORK LOAD ÷ = 70% of Max. Cap.	MA.	9000	120	98.8	100.8	101.3	
			120	97.7	101.2	101.2	
			87	99.5	101.0	101.1x	
	DA.	8000	125	97.8	100.4	100.3x	
			121	98.2	99.9	100.4x	
			122	97.5	99.7	100.2x	
	ZE.	7000	120	98.7	100.9	100.8	
			155	99.4	100.9	101.3	101.4x
			120	98.8	100.5	100.6	
RELATIVE WORK LOAD ÷ = 80% of Max. Cap.	MA.	11000	40	99.7	102.0x		
			36	-	101.8x		
			32	98.5	100.9x		
	DA.	10000	33	99.6	100.2x		
			35	99.9	100.6x		
			34	98.8	100.5x		
	ZE.	8500	52	98.8	100.3x		
			57	99.9	100.8x		
			58	99.1	100.7		
RELATIVE WORK LOAD ÷ = 90% of Max. Cap.	MA.	12000	16	-	99.4x		
			18	-	100.7x		
			17	-	98.8x		
	DA.	10500	28	-	100.4x		
			27	98.8	100.0x		
			28	97.7	99.9x		
	ZE.	9000	30	-	100.5x		
			28	-	100.5x		
			29	99.4	100.5x		

GROUPED DATA - PYRUVIC ACID (mM per litre blood water) x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240	360	480
RELATIVE WORK LOAD ÷ = 40% of Max. Cap.	MA.	5000	480+	0.123	0.098	0.106	0.092	0.142
			480+	0.089	0.125	0.068	0.104	0.123
			480+	0.084	0.130	0.114	0.126	0.117
	DA.	5000	480+	0.084	0.074	0.110	0.105	0.157
			480+	0.119	0.089	0.086	0.188	0.143
			480+	0.120	0.117	0.085	0.062	0.107
	ZE.	4000	480+	0.120	0.225	0.155	0.120	0.261
			480+	0.138	0.243	0.153	0.130	0.160
			480+	0.211	0.112	0.149	0.141	0.110
RELATIVE WORK LOAD ÷ = 50% of Max. Cap.	MA.	6500	401	-	0.118	0.105	0.106	0.123x
			395	-	0.129	0.126	0.079	0.122x
			361	-	0.135	0.075	0.142x	
	DA.	6000	480	-	-	-	-	0.244
			480	-	0.064	0.111	0.109	0.147
			480	-	0.123	0.106	0.155	0.120
	ZE.	5000	480	0.131	0.216	0.135	0.200	0.253
			480	0.136	0.116	0.192	0.164	0.161
			480	0.187	0.150	0.156	0.108	0.150
RELATIVE WORK LOAD ÷ = 55% of Max. Cap.	MA.	7000	339	0.142	0.127	0.100	0.158x	
			295	0.128	0.083	0.078	0.074x	
			332	0.141	0.098	0.081	0.096x	
	DA.	6500	333	-	0.153	0.093	0.059x	
			347	-	0.087	0.102	0.091x	
			324	-	0.109	0.080	0.124x	
	ZE.	5500	437	-	0.141	0.156	0.136	0.163x
			336	-	0.150	0.168	0.219x	
			336	-	0.139	0.081	0.159x	
RELATIVE WORK LOAD ÷ = 60% of Max. Cap.	MA.	8000	201	-	0.088	0.125x		
			190	-	0.103	0.101x		
			244	-	0.076	0.093x		
	DA.	7000	240	0.104	0.065	0.098		
			284	0.142	0.113	0.124	0.127x	
			270	0.104	0.122	0.082	0.103x	
	ZE.	6000	332	0.161	0.176	0.184	0.143x	
			301	0.191	0.207	0.192	0.137x	
			246	0.175	0.236	0.358x		

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	360
RELATIVE WORK LOAD ÷ = 70% of Max. Cap.	MA.	9000	120	0.130	0.138	
			120	0.131	0.172	
			87	0.141	0.109x	
	DA.	8000	125	-	0.158x	
			121	-	0.130x	
			122	-	0.113x	
	ZE.	7000	120	0.216	0.335	
			155	0.217	0.205	0.198x
			120	0.257	0.276	
RELATIVE WORK LOAD ÷ = 80% of Max. Cap.	MA.	11000	40	0.164	0.249x	
			36	0.138	0.205x	
			32	0.261	0.270x	
	DA.	10000	33	-	0.308x	
			35	-	0.260x	
			34	-	0.275x	
	ZE.	8500	52	-	0.261x	
			57	-	0.260x	
			58	-	0.342x	
RELATIVE WORK LOAD ÷ = 90% of Max. Cap.	MA.	12000	16	-	0.314x	
			18	-	0.313x	
			17	-	0.360x	
	DA.	10500	28	-	0.232x	
			27	-	0.263x	
			28	-	0.344x	
	ZE.	9000	30	0.341	0.448x	
			28	0.445	0.452x	
			29	0.394	0.443x	
RELATIVE WORK LOAD ÷ = 100% of Max. Cap.	MA.	14000	4	0.445x		
			4	-		
			4	-		
	DA.	13000	5	0.274x		
			4.5	0.293x		
			4.5	0.352x		
	ZE.	10000	4.5	0.271x		
			4.5	0.390x		
			4.5	0.518x		

TABLE XI

GROUPED DATA - LACTIC ACID (mM per litre blood water)

x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240	360	480
RELATIVE WORK LOAD ÷ = 40% of Max. Cap.	MA.	5000	480+	0.811	0.924	0.907	0.705	0.978
			480+	0.713	0.861	0.607	0.735	0.609
			480+	0.896	0.998	0.766	0.774	0.733
	DA.	5000	480+	0.984	0.671	0.714	0.683	0.868
			480+	0.663	0.594	0.574	0.788	1.005
			480+	0.763	0.722	0.746	0.599	0.772
	ZE.	4000	480+	0.810	1.321	0.839	0.910	1.092
			480+	1.200	1.425	1.093	0.899	0.967
			480+	1.475	0.657	0.779	0.653	0.858
RELATIVE WORK LOAD ÷ = 50% of Max. Cap.	MA.	6500	401	-	0.901	0.664	0.754	0.874x
			395	-	0.889	0.812	0.840	0.851x
			361	-	1.101	0.565	1.211x	
	DA.	6000	480	-	-	-	-	-
			480	-	0.776	0.919	1.003	1.167
			480	-	0.825	0.784	0.631	0.915
	ZE.	5000	480	0.709	1.147	1.159	1.070	1.738
			480	1.309	1.288	1.151	0.987	1.200
			480	1.391	0.981	0.914	0.963	0.975
RELATIVE WORK LOAD ÷ = 55% of Max. Cap.	MA.	7000	339	0.895	0.495	0.789	1.080x	
			295	0.864	0.947	0.922	0.797x	
			332	1.391	0.829	0.695	0.738x	
	DA.	6500	333	-	1.103	0.867	0.695x	
			347	-	0.743	0.678	0.666x	
			324	-	0.588	0.598	1.040x	
	ZE.	5500	437	-	0.995	1.250	1.019	1.242x
			336	-	1.096	1.311	1.136x	
			336	-	1.297	0.793	1.257x	
RELATIVE WORK LOAD ÷ = 60% of Max. Cap.	MA.	8000	201	-	0.770	0.948x		
			190	-	0.869	1.118x		
			244	-	0.738	0.879x		
	DA.	7000	240	0.949	0.571	0.744		
			284	0.897	0.936	1.067	1.009x	
			270	0.734	1.099	0.912	0.865x	
	ZE.	6000	332	1.103	1.260	1.009	1.328x	
			301	1.830	1.465	1.604	1.044x	
			246	1.325	2.128	3.154x		

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240
RELATIVE WORK LOAD ÷ = 70% of Max. Cap.	MA.	9000	120	1.045	0.859	
			120	1.276	1.281	
			87	1.445	1.488x	
	DA.	8000	125	-	1.082x	
			121	-	1.331x	
			122	-	1.086x	
	ZE.	7000	120	2.450	3.676	
			155	1.847	2.187	1.934x
			120	2.150	2.506	
RELATIVE WORK LOAD ÷ = 80% of Max. Cap.	MA.	11000	40	1.764	4.333x	
			36	4.080	3.086x	
			32	5.367	4.203x	
	DA.	10000	33	-	5.477x	
			35	-	3.853x	
			34	-	5.672x	
	ZE.	8500	52	-	6.709x	
			57	-	4.361x	
			58	-	5.710x	
RELATIVE WORK LOAD ÷ = 90% of Max. Cap.	MA.	12000	16	-	6.901x	
			18	-	5.976x	
			17	-	6.565x	
	DA.	10500	28	-	7.252x	
			27	-	4.932x	
			28	-	6.533x	
	ZE.	9000	30	5.929	12.731x	
			28	8.949	10.255x	
			29	8.087	12.299x	
RELATIVE WORK LOAD ÷ = 100% of Max. Cap.	MA.	14000	4	10.179x		
			4	-		
			4	-		
	DA.	13000	5	6.684x		
			4.5	8.221x		
			4.5	11.494x		
	ZE.	10000	4.5	8.884x		
			4.5	10.821x		
			4.5	10.623x		

GROUPED DATA - EXCESS LACTATE (ml per litre blood water) x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240	360	480
RELATIVE WORK LOAD +- 40% of Max. Cap.	MA.	5000	480+	0.132	0.098	0.016	-0.066	-0.212
			480+	0.250	-0.270	-0.008	-0.286	-0.563
			480+	-0.245	0.131	0.086	-0.866	-0.047
	DA.	5000	480+	0.322	0.154	-0.060	-0.057	-0.235
			480+	-0.240	0.017	-0.046	-0.062	-0.026
			480+	-0.183	-0.364	-0.043	0.024	-0.221
	ZE.	4000	480+	0.160	0.048	-0.043	0.227	-0.389
			480+	0.071	-0.592	-0.177	-0.189	-0.361
			480+	-0.155	-0.210	-0.375	-0.439	-0.086
RELATIVE WORK LOAD +- 50% of Max. Cap.	MA.	6500	481	-	0.185	0.044	0.039	0.044x
			395	-	0.852	0.357	0.328	0.060x
			361	-	-0.623	-0.060	0.028x	
	DA.	6000	480	-	-	-	-	0.773
			480	-	0.227	0.053	0.068	0.095
			480	-	0.011	-0.008	-0.373	0.118
	ZE.	3000	480	-0.001	-0.576	0.083	-0.521	-0.272
			480	0.188	0.449	-0.236	-0.283	0.037
			480	-0.054	0.122	0.104	0.392	0.196
RELATIVE WORK LOAD +- 55% of Max. Cap.	MA.	7000	339	0.112	0.348	0.124	0.029x	
			295	0.198	0.283	0.291	-0.198x	
			332	-0.549	0.194	0.170	0.108x	
	DAc	6500	333	-	-0.143	0.109	0.214x	
			347	-	0.001	-0.191	-0.118x	
			324	-	-0.415	-0.138	-0.973x	
	ZE.	5500	437	-	-0.080	0.459	-0.018	0.000x
			336	-	-0.188	-0.127	-0.745x	
			336	-	-0.240	-0.183	-0.508x	
RELATIVE WORK LOAD +- 60% of Max. Cap.	MA.	8000	201	-	0.056	-0.073x		
			198	-	-0.071	0.285x		
			244	-	0.199	0.228x		
	DA.	7000	240	0.138	0.012	-0.097		
			284	-0.181	-0.038	0.608	-0.875x	
			270	-0.017	-0.113	0.095	-0.158x	
	ZE.	6000	332	0.231	-0.076	-0.295	0.246x	
			301	0.268	-0.669	-0.375	-0.368x	
			246	-0.027	0.659	0.927x		

	SUBJECT	WORK RATE	ENDURANCE TIME	9	120	240
RELATIVE WORK LOAD +- 70% of Max. Cap.	MA.	9000	120	0.328	0.029	
			120	0.595	-0.262	
			87	-0.495	0.720x	
	DA.	8000	125	-	0.155x	
			121	-	-0.040x	
			122	-	0.381x	
	ZE.	7000	120	0.154	0.663	
			155	0.072	0.587	0.311x
			120	-0.107	0.367	
RELATIVE WORK LOAD +- 80% of Max. Cap.	MA.	11000	40	0.859	2.481x	
			36	3.362	1.531x	
			32	2.196	1.278x	
	DA.	10000	33	-	2.573x	
			35	-	1.178x	
			34	-	2.865x	
	ZE.	8500	52	-	3.959x	
			57	-	1.902x	
			58	-	3.131x	
RELATIVE WORK LOAD +- 90% of Max. Cap.	MA.	12000	16	-	4.072x	
			18	-	3.710x	
			17	-	3.476x	
	DA.	10500	28	-	4.713x	
			27	-	2.887x	
			28	-	3.592x	
	ZE.	9000	30	3.140	8.134x	
			28	5.500	6.286x	
			29	3.922	8.875x	
RELATIVE WORK LOAD +- 100% of Max. Cap.	MA.	14000	4	4.727x		
			4	-		
			4	-		
	DA.	13000	5	4.525x		
			4.5	5.619x		
			4.5	8.282x		
	ZE.	10000	4.5	6.819x		
			4.5	7.888x		
			4.5	6.717x		

TABLE XIII

GROUPED DATA - BLOOD GLUCOSE (mg per 100 ml)

x Terminal value as at end of endurance time.

	SUBJECT	WORK RATE	ENDURANCE TIME	120	240	360	480
RELATIVE WORK LOAD ± 40% of Max. Cap.	MA.	5000	480+	61.8	65.1	61.0	58.8
			480+	70.8	65.5	57.5	64.3
			480+	69.4	61.3	58.8	62.3
	DA.	5000	480+	66.6	60.7	56.8	55.1
			480+	67.6	61.3	62.7	65.0
			480+	71.9	69.7	60.7	64.3
	ZE.	4000	480+	55.3	51.4	52.1	56.6
			480+	63.4	65.0	62.1	55.9
			480+	61.0	69.8	62.2	58.3
RELATIVE WORK LOAD ± 50% of Max. Cap.	MA.	6500	401	69.4	67.8	59.4	54.6x
			395	69.7	57.4	58.3	55.8
			361	62.8	62.5	52.9x	
	DA.	6000	480	-	-	-	48.4
			480	76.1	69.4	65.7	59.4
			480	67.2	56.7	59.2	52.5
	ZE.	5000	480	57.8	54.5	49.3	29.8
			480	60.2	56.7	50.3	49.8
			480	73.1	59.1	53.8	53.1
RELATIVE WORK LOAD ± 55% of Max. Cap.	MA.	7000	339	78.8	57.7	54.1x	
			295	74.2	65.4	71.8x	
			332	59.9	50.8	39.9x	
	DA.	6500	333	65.2	66.8	56.8x	
			347	-	66.0	-	
			324	70.8	63.8	61.9x	
	ZE.	5500	437	68.1	61.3	55.1	52.2x
			336	60.8	52.6	46.9x	
			336	59.2	62.5	54.4x	
RELATIVE WORK LOAD ± 60% of Max. Cap.	MA.	8000	281	66.7	60.4x		
			198	56.9	55.8x		
			244	-	56.4x		
	DA.	7000	240	70.9	74.8		
			284	82.5	73.4	66.8x	
			270	67.9	66.2	62.1x	
	ZE.	6000	332	57.4	54.3	48.9x	
			301	62.9	55.7	-	
			246	61.1	58.5x		

	SUBJECT	WORK RATE	ENDURANCE TIME	120	240
RELATIVE WORK LOAD ± 70% of Max. Cap.	MA.	9000	120	62.8	
			120	65.5	
			87	79.7x	
	DA.	8000	125	72.9x	
			121	82.6x	
			122	59.4x	
	ZE.	7000	120	50.9	
			155	57.8	61.4x
			120	58.8	
RELATIVE WORK LOAD ± 80% of Max. Cap.	MA.	11000	40	81.8x	
			36	81.4x	
			32	85.8x	
	DA.	10000	33	71.9x	
			35	76.1x	
			34	74.2x	
	ZE.	8500	52	76.4x	
			57	48.8x	
			58	59.9x	
RELATIVE WORK LOAD ± 90% of Max. Cap.	MA.	12000	16	73.7x	
			18	66.7x	
			17	70.8x	
	DA.	10500	28	77.9x	
			27	78.5x	
			28	70.1x	
	ZE.	9000	30	77.5x	
			28	67.2x	
			29	70.0x	

TABLE XIV

SUBJECT FR. OXYGEN INTAKE (Litres per minute)

RELATIVE WORK LOAD	WORK RATE	END. TIME	9	120	240	360	480
± 40% of	4000	480	1.09	1.30	1.38	1.40	1.46
Maximum		480	1.19	1.28	-	1.40	1.42
Capacity		480	1.19	1.42	1.22	1.16	1.32
± 50% of	4500	330	-	1.41	1.52	1.52x	
Maximum		330	-	1.40	1.47	1.48x	
Capacity		300	-	1.45	1.46	1.49x	
± 55% of	5000	240	1.48	-	1.78		
Maximum		240	1.44	-	1.68		
Capacity		240	1.36	1.60	1.67		
± 60% of	6000	120	1.74	1.94			
Maximum		120	1.65	1.87			
Capacity		160	1.64	1.82	2.03x		
± 70% of	7000	107	1.91	2.15x			
Maximum		67	2.00	1.97x			
Capacity		76	1.86	2.23x			
± 80% of	9000	18	-	2.48x			
Maximum		27	2.60	2.61x			
Capacity		29	2.51	2.62x			
± 90% of	10000	5.5	2.77x				
Maximum		5	2.80x				
Capacity		5	2.89x				
± 100% of	11000	4	3.80x				
Maximum		3	2.98x				
Capacity		3	3.11x				

x Terminal value as at end of endurance time.

TABLE XV

SUBJECT FR. EXCESS LACTATE (mM per litre blood water)

RELATIVE WORK LOAD	WORK RATE	END. TIME	9	120	240	360	480
± 40% of	4000	480	-0.082	-0.438	-0.452	-0.215	-0.679
Maximum		480	0.123	-0.108	-0.172	-0.213	-0.195
Capacity		480	0.182	-0.118	-0.316	-0.444	-0.512
± 50% of	4500	330	-	-0.167	-0.415	-0.217x	
Maximum		330	-	-0.279	-0.334	-0.557x	
Capacity		300	-	0.191	-0.180	-0.275x	
± 55% of	5000	240	0.241	-	0.181		
Maximum		240	0.069	-	0.847		
Capacity		240	0.243	-0.341	0.813		
± 60% of	6000	120	0.293	-0.359x			
Maximum		120	0.346	0.238x			
Capacity		160	0.726	-0.088	-0.155x		
± 70% of	7000	107	1.448	2.188x			
Maximum		67	0.591	0.661x			
Capacity		76	-0.188	2.089x			
± 80% of	9000	18	5.439	10.695x			
Maximum		27	6.879	5.357x			
Capacity		29	7.093	5.452x			

x Terminal value as at end of endurance time.

TABLE XVI

SUBJECT FR. BLOOD GLUCOSE (mg per 100 ml)

RELATIVE WORK LOAD	WORK RATE	END. TIME	120	240	360	480
± 40% of	4000	480	68.7	54.4	51.9	45.8
Maximum		480	73.1	56.3	66.1	62.4
Capacity		480	69.9	61.4	63.5	52.9
± 50% of	4500	330	64.6	51.6	51.8x	
Maximum		330	70.2	59.1	61.6x	
Capacity		300	65.4	52.1	48.2x	
± 55% of	5000	240	-	61.2		
Maximum		240	-	37.5		
Capacity		240	61.9	57.3		
± 60% of	6000	120	71.9x			
Maximum		120	65.2x			
Capacity		160	55.2	58.1x		
± 70% of	7000	107	63.3x			
Maximum		67	76.4x			
Capacity		76	63.3x			
± 80% of	9000	18	75.5			
Maximum		27	62.9			
Capacity		29	64.1			

x Terminal value as at end of endurance time.

TABLE XVII SUBJECT FR. RECTAL TEMPERATURE (°F)

RELATIVE WORK LOAD	WORK RATE	END. TIME	15	60	120	180	240	300	360	420	480
± 40% of	4000	480	98.9	99.3	99.5	99.9	100.0	99.7	99.8	99.8	99.9
Maximum		480	96.4	99.5	100.1	100.2	100.8	100.8	100.6	-	101.0
Capacity		480	97.4	98.8	99.5	-	99.5	99.8	100.0	99.4	99.9
± 50% of	4500	330	98.8	100.2	100.0	99.9	99.2	97.6	97.4x		
Maximum		330	99.3	99.9	100.4	100.0	100.4	100.2	100.6x		
Capacity		300	97.9	99.6	100.1	99.6	100.1	99.6x			
± 55% of	5000	240	-	-	-	100.6	100.7				
Maximum		240	99.0	99.3	97.9	99.2	-				
Capacity		240	98.4	100.7	100.6	100.7	101.3				
± 60% of	6000	120	101.1	100.7	100.7						
Maximum		120	98.5	100.6	101.2						
Capacity		160	-	99.7	100.0	100.2x					
± 70% of	7000	107	98.3	100.2	100.4x						
Maximum		67	98.1	101.6x							
Capacity		76	97.7	99.5	100.5x						
± 80% of	9000	18	-	100.1x							
Maximum		27	99.3	100.4x							
Capacity		29	98.6	99.6x							

x Terminal value as at end of endurance time.

TABLE XVIII SUBJECT FR. HEART RATE (Beats per minute)

RELATIVE WORK LOAD	WORK RATE	END. TIME	9	15	60	120	180	240	300	360	420	480
± 40% of	4000	480	106	124	116	119	123	128	129	138	132	141
Maximum		480	119	121	130	131	131	143	143	149	149	153
Capacity		480	102	110	116	121	122	130	123	130	131	142
± 50% of	4500	330	-	127	134	138	139	149	143	142x		
Maximum		330	-	137	126	129	134	142	141	145x		
Capacity		300	-	125	134	143	143	150	152x			
± 55% of	5000	240	125	145	150	154	158	167				
Maximum		240	122	136	142	144	152	158				
Capacity		240	119	135	134	134	150	158				
± 60% of	6000	120	136	138	140	149						
Maximum		120	137	152	156	161						
Capacity		160	130	137	141	147	158x					
± 70% of	7000	107	153	158	156	168x						
Maximum		67	150	155	163x							
Capacity		76	151	148	159	172x						
± 80% of	9000	18	184	-	186x							
Maximum		27	176	172	176x							
Capacity		29	184	173	178x							
± 90% of	10000	5.5	178x									
Maximum		5	183x									
Capacity		5	188x									
± 100% of	11000	4	182x									
Maximum		3	189x									
Capacity		3	179x									

x Terminal value as at end of endurance time.

TABLE XIX

SUBJECT FR. LACTIC ACID (mM per litre blood water)

RELATIVE WORK LOAD	WORK RATE	ENDURANCE TIME	9	120	240	360	480
± 40% of	4000	480	0.906	0.971	0.720	1.239	1.259
Maximum		480	1.161	0.761	0.953	0.726	1.185
Capacity		480	1.259	0.972	0.876	0.985	0.916
± 50% of	4500	330	-	0.685	1.242	1.685x	
Maximum		330	-	0.881	0.837	0.614x	
Capacity		300	-	0.939	1.454	1.359x	
± 55% of	5000	240	1.462	-	1.888		
Maximum		240	1.199	-	2.373		
Capacity		240	1.394	1.213	1.170		
± 60% of	6000	120	1.864	1.536x			
Maximum		120	1.785	1.295x			
Capacity		160	1.838	0.897	1.090x		
± 70% of	7000	107	3.885	4.257x			
Maximum		67	2.647	3.748x			
Capacity		76	3.689	4.736x			
± 80% of	9000	18	5.619	13.383x			
Maximum		27	5.093	10.398x			
Capacity		29	4.536	8.160x			

x Terminal value as at end of endurance time.

TABLE XX

SUBJECT FR. PYRUVIC ACID (mM per litre blood water)

RELATIVE WORK LOAD	WORK RATE	ENDURANCE TIME	9	120	240	360	480
± 40% of	4000	480	0.144	0.155	0.129	0.160	0.211
Maximum		480	0.124	0.137	0.175	0.148	0.206
Capacity		480	0.112	0.097	0.186	0.120	0.127
± 50% of	4500	330	-	0.184	0.282	0.215x	
Maximum		330	-	0.112	0.113	0.113x	
Capacity		300	-	0.092	0.201	0.201x	
± 55% of	5000	240	0.178	-	0.287		
Maximum		240	0.135	-	0.218		
Capacity		240	0.122	0.145	0.185		
± 60% of	6000	120	0.229	0.181x			
Maximum		120	0.172	0.164x			
Capacity		160	0.117	0.095	0.121x		
± 70% of	7000	107	0.187	0.258x			
Maximum		67	0.218	0.248x			
Capacity		76	0.385	0.284x			
± 80% of	9000	18	0.398	0.318x			
Maximum		27	0.331	0.383x			
Capacity		29	0.330	0.331x			

x Terminal value as at end of endurance time.

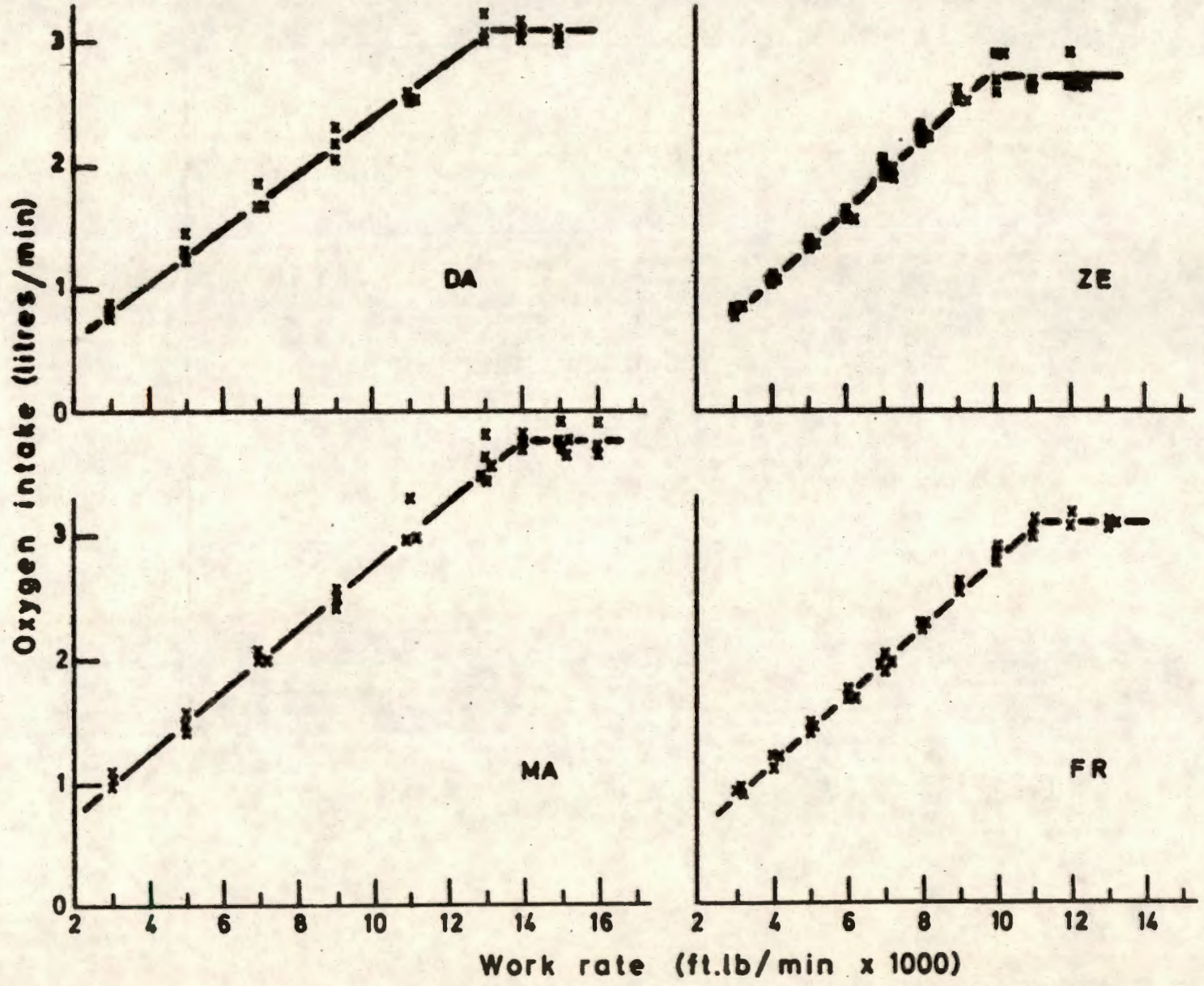

Fig. 1 Maximum oxygen intake of the four subjects.

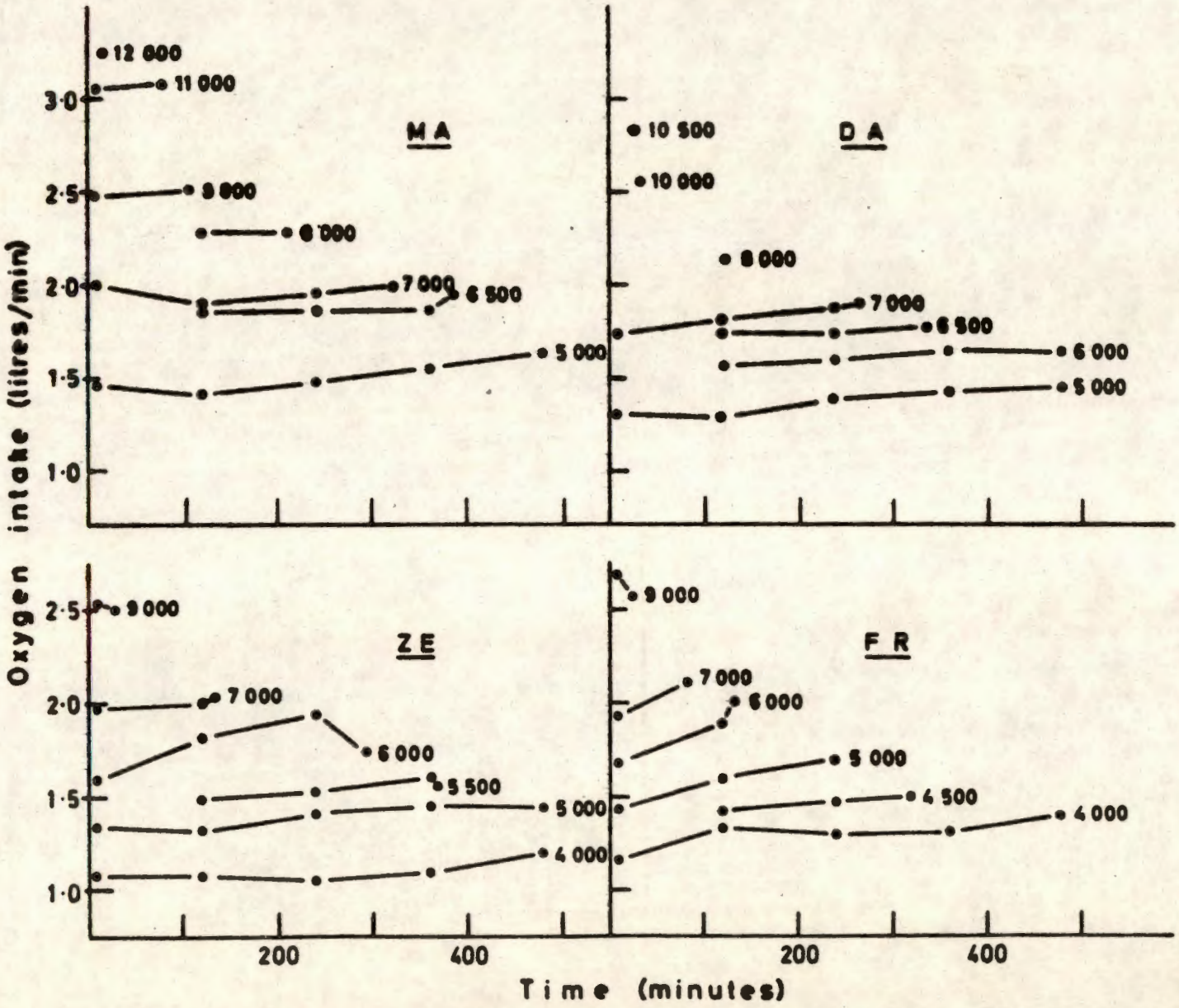

Fig. 2 Oxygen intake relative to time at various work loads.

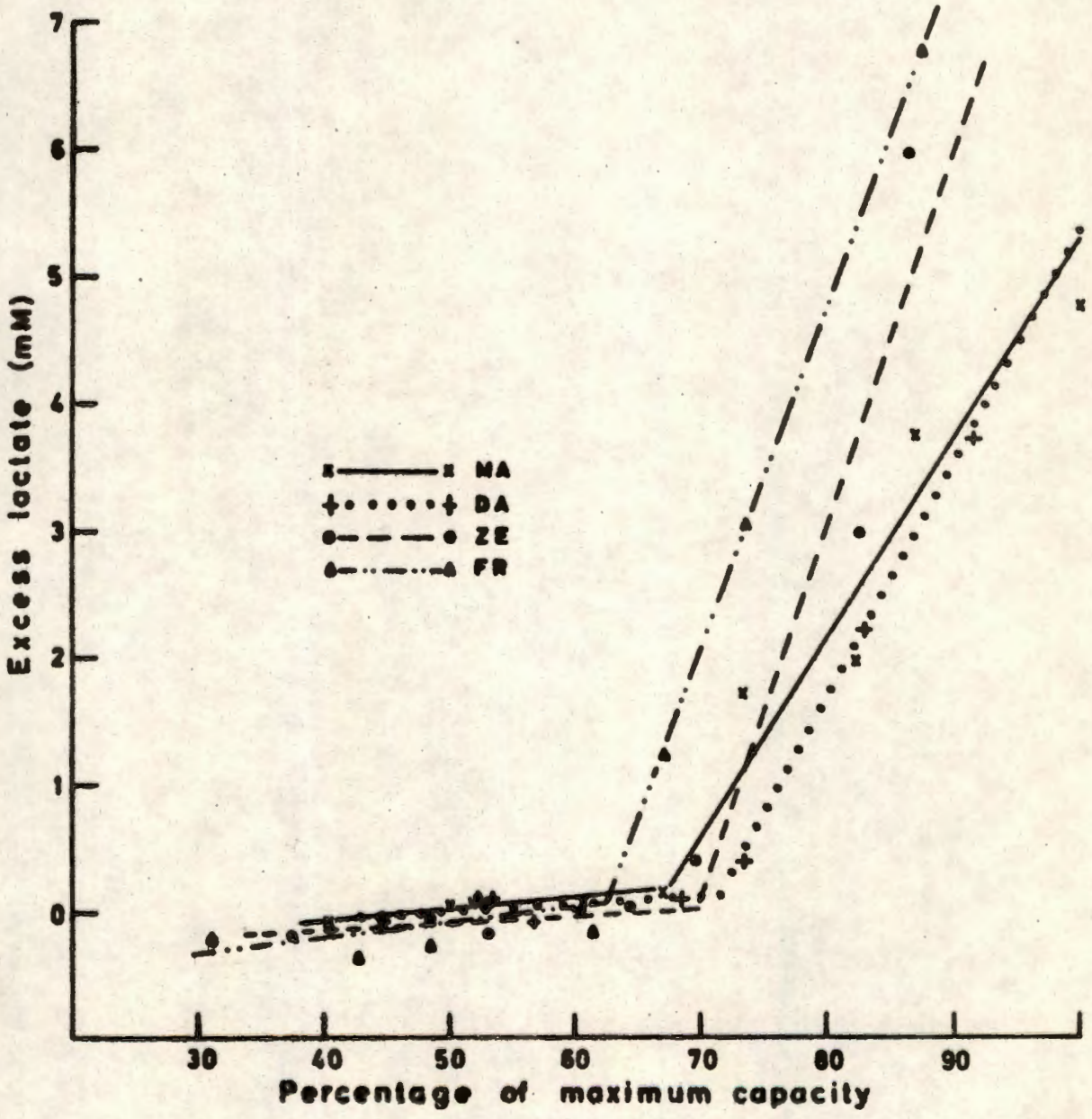

Fig. 3 Excess lactate relative to work load.

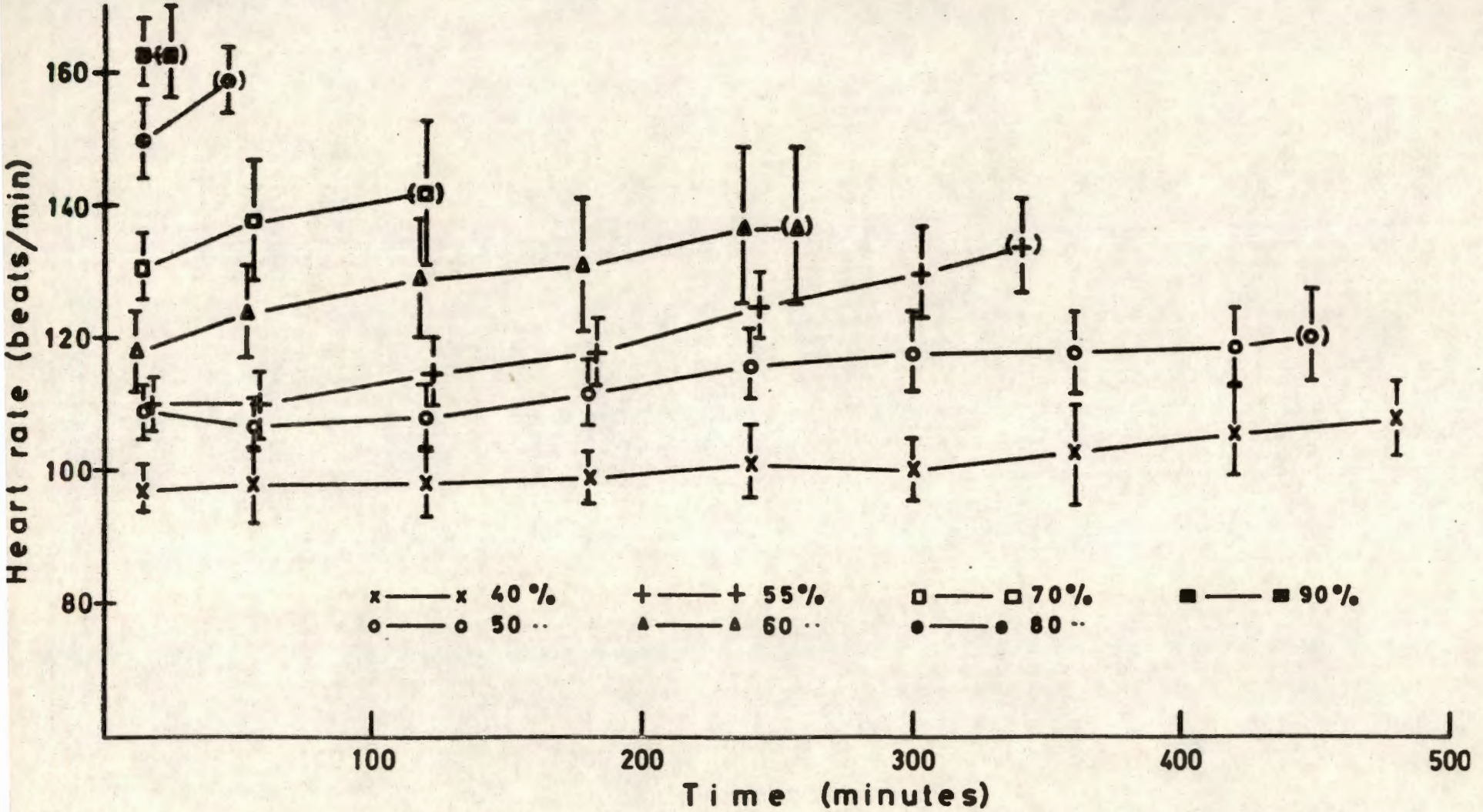

Fig. 4a Heart rate relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

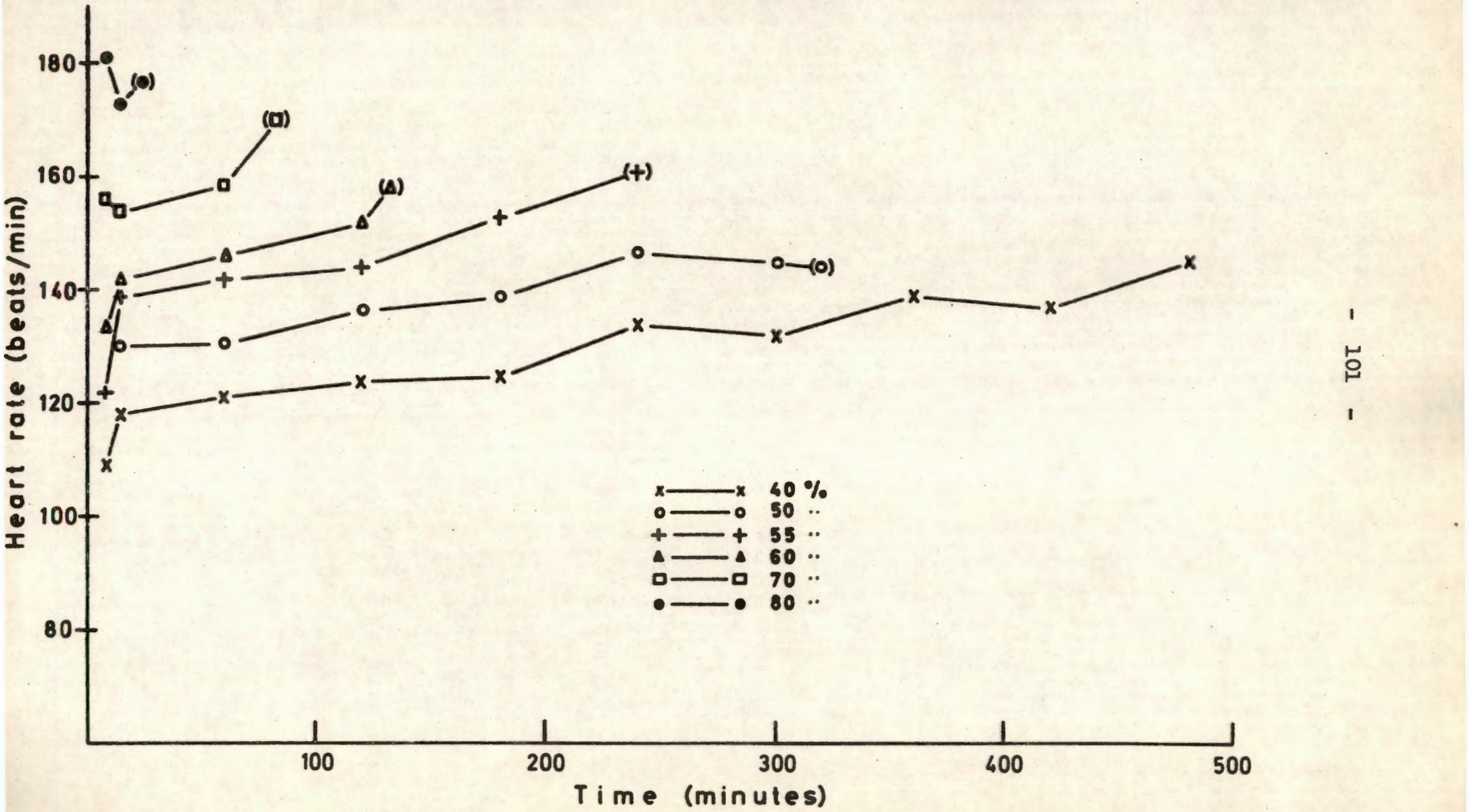

Fig. 4b Heart rate relative to time at various levels of aerobic capacity. (Subject FR).

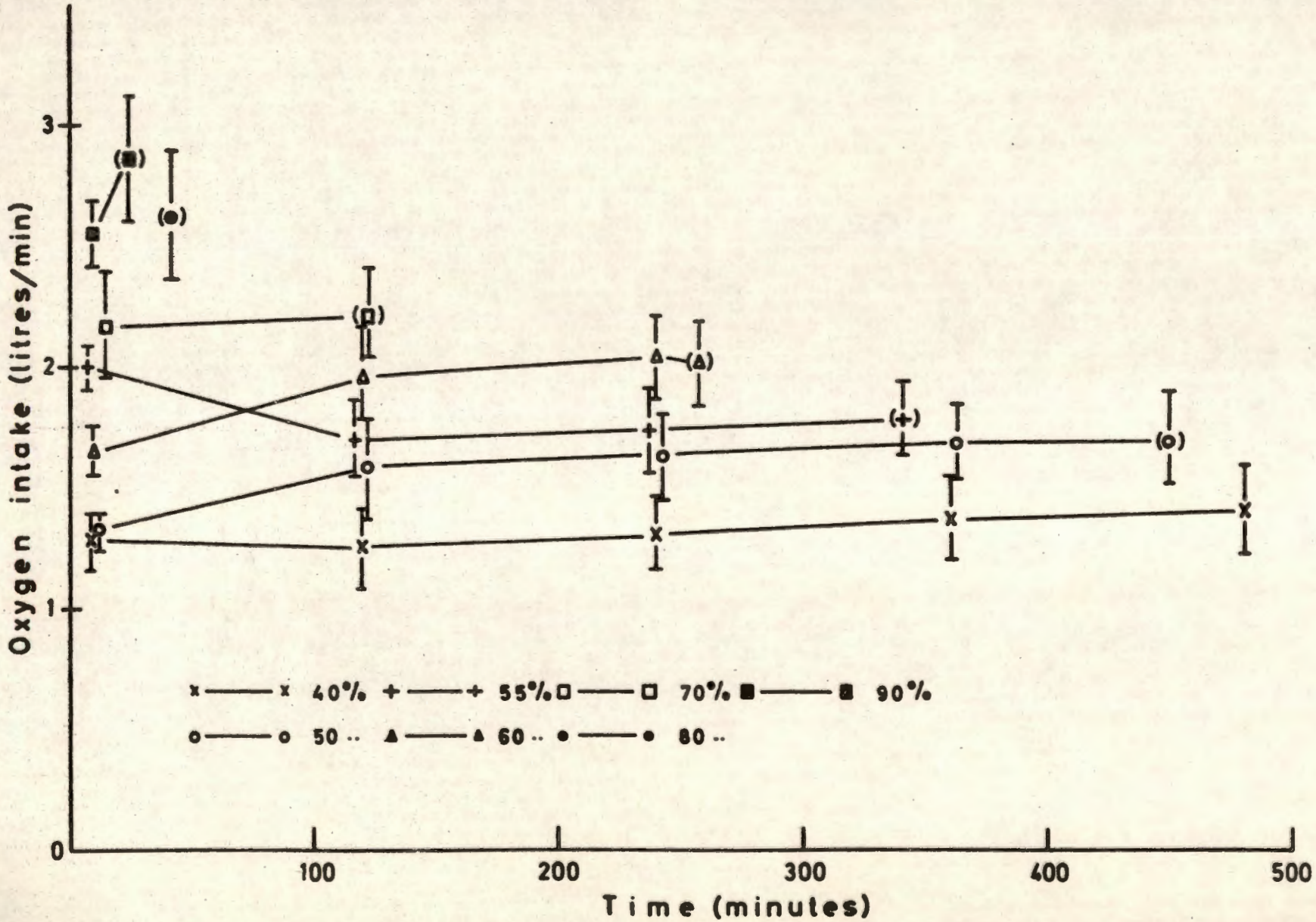

Fig. 5a Oxygen intake relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

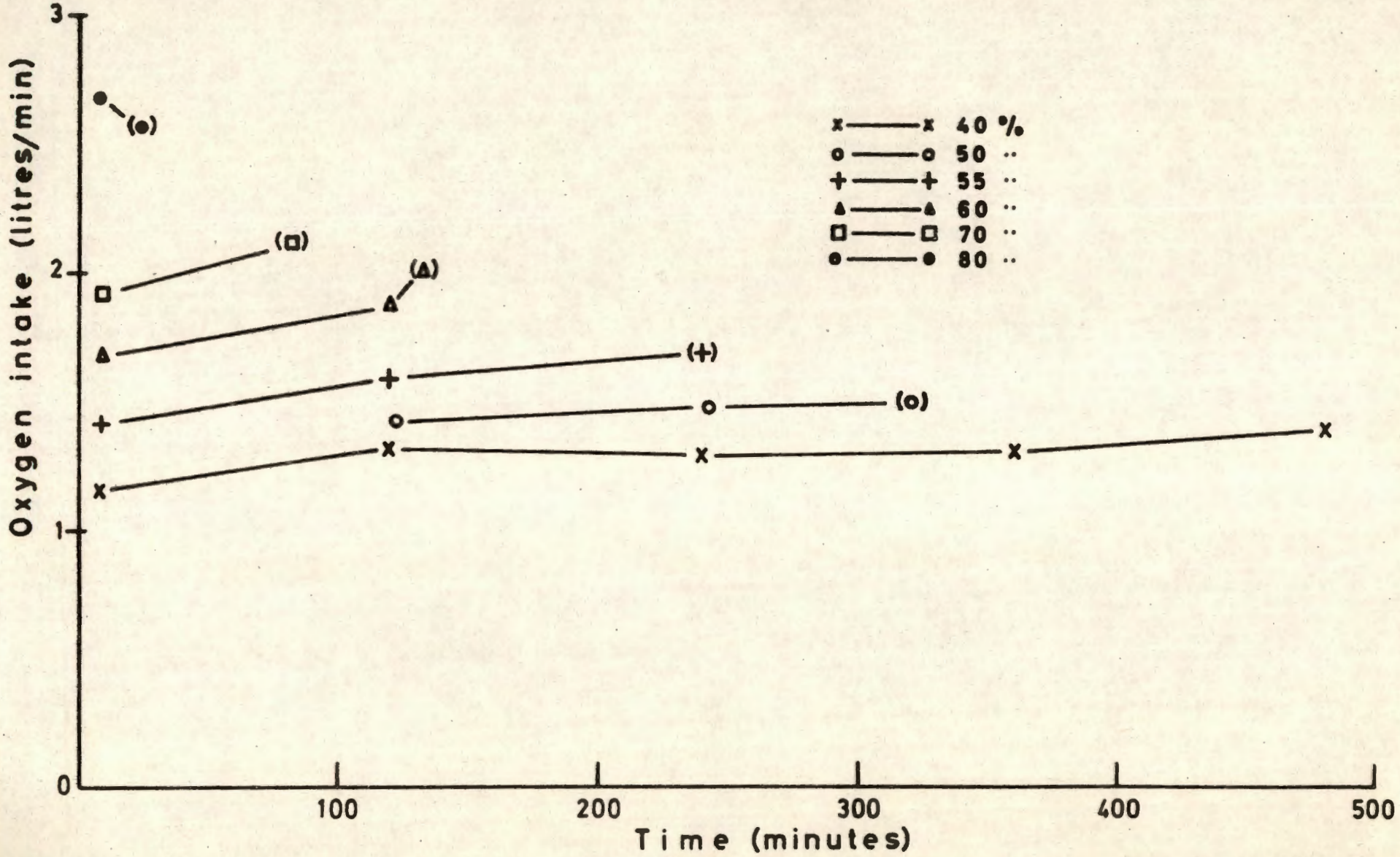

Fig. 5b Oxygen intake relative to time at various levels of aerobic capacity. (Subject FR).

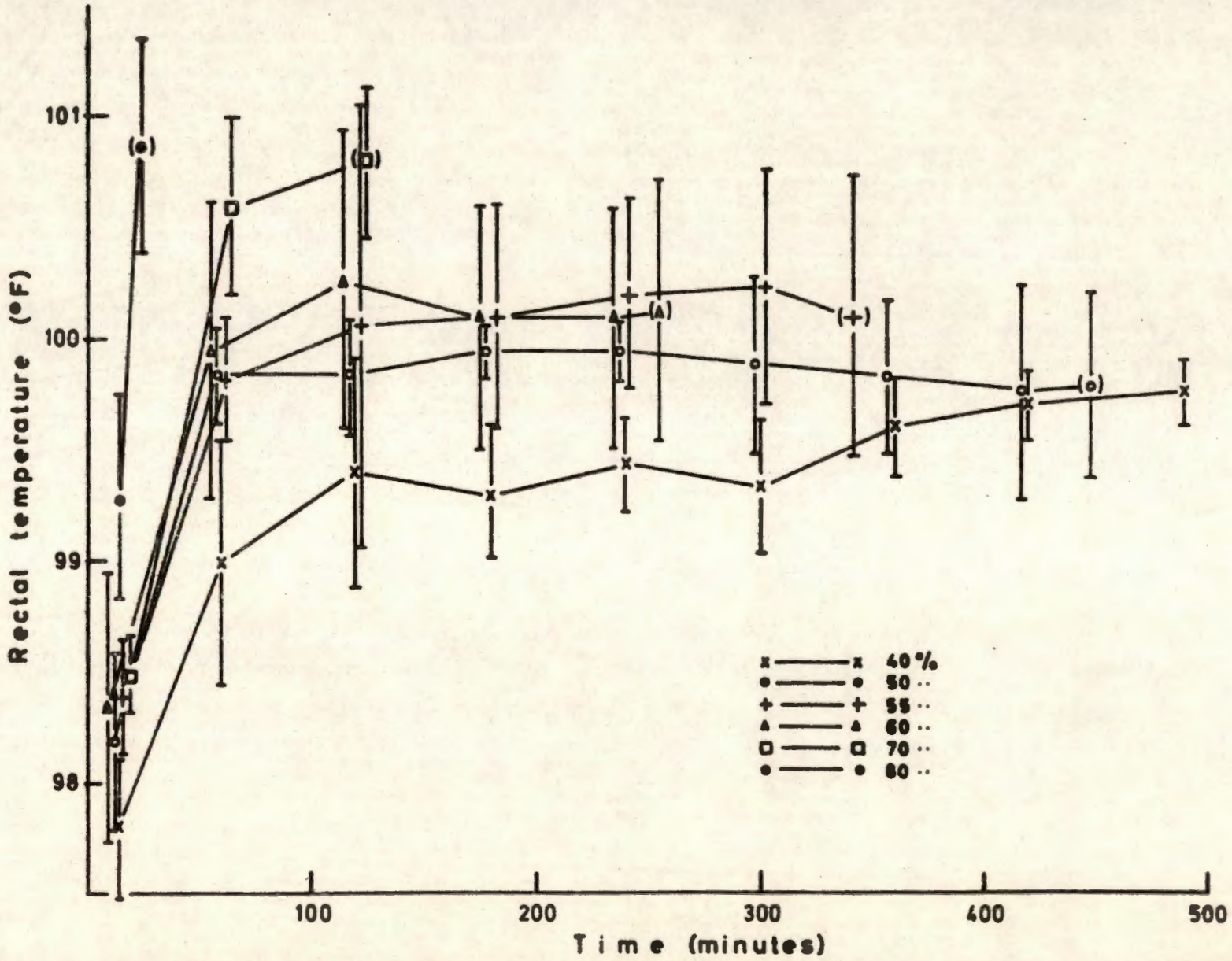

Fig. 6a Rectal temperature relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

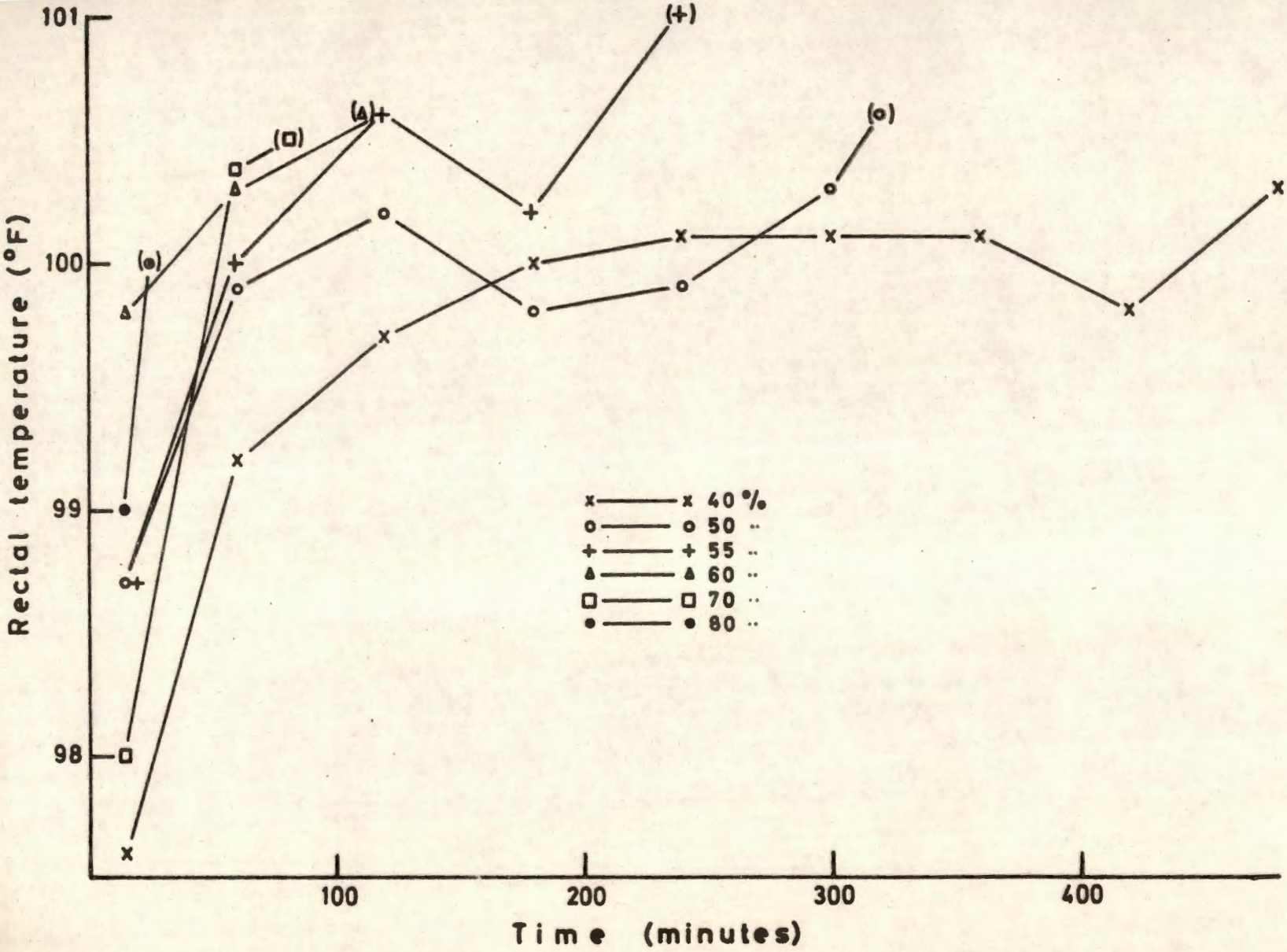

Fig. 6b Rectal temperature relative to time at various levels of aerobic capacity. (Subject FR).

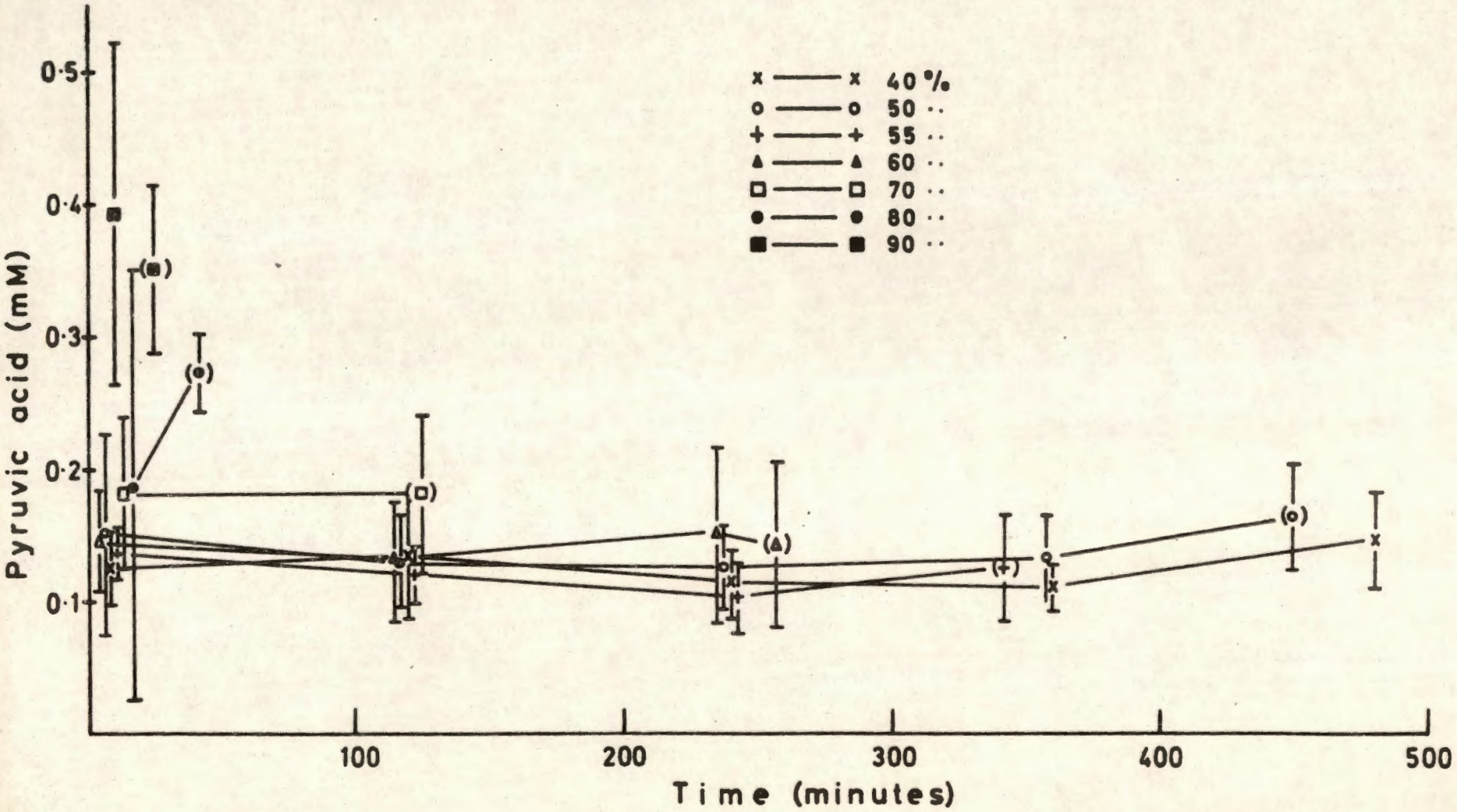

Fig. 7a Pyruvic acid relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

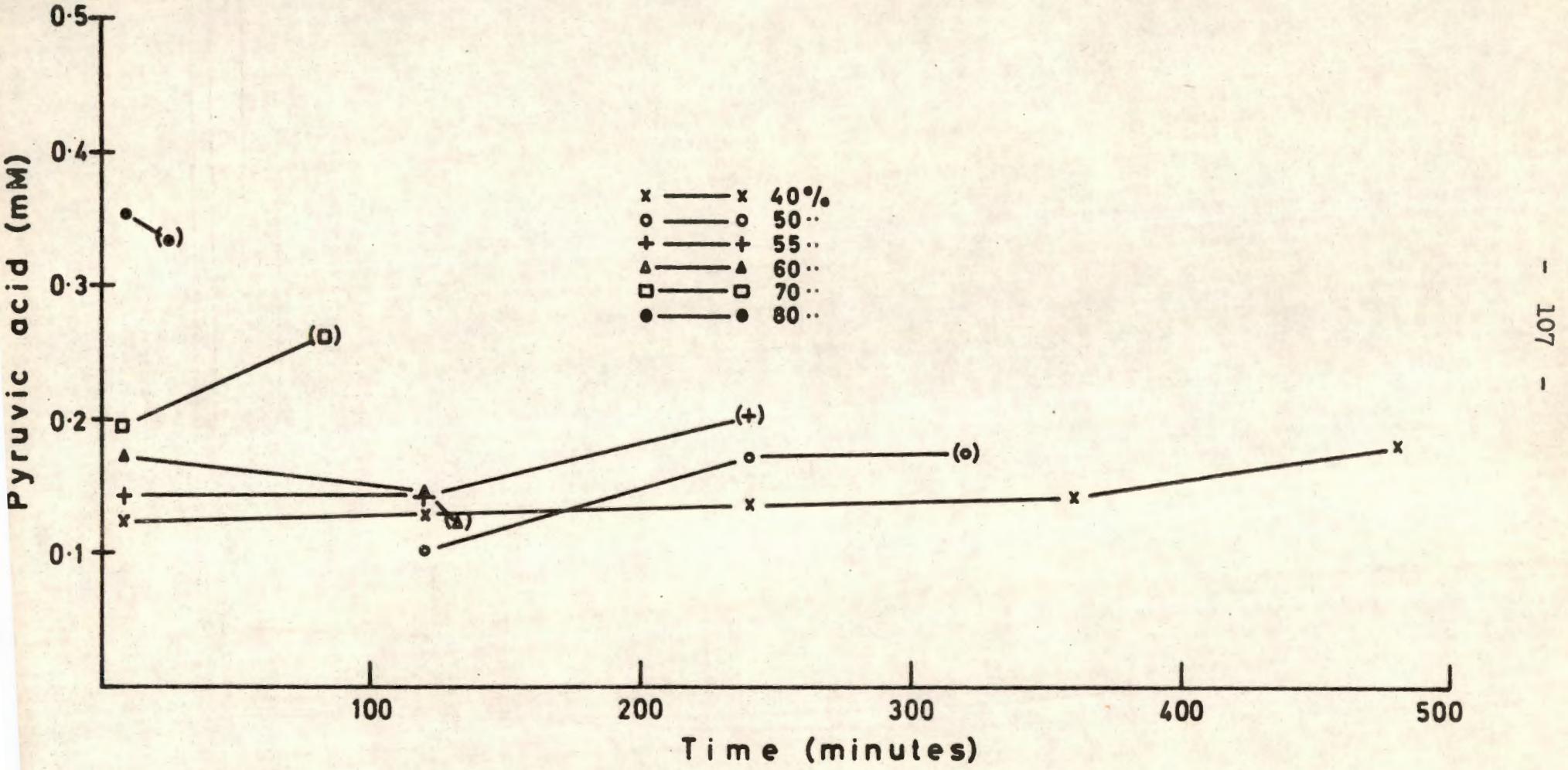

Fig. 7b Pyruvic acid relative to time at various levels of aerobic capacity. (Subject FR).

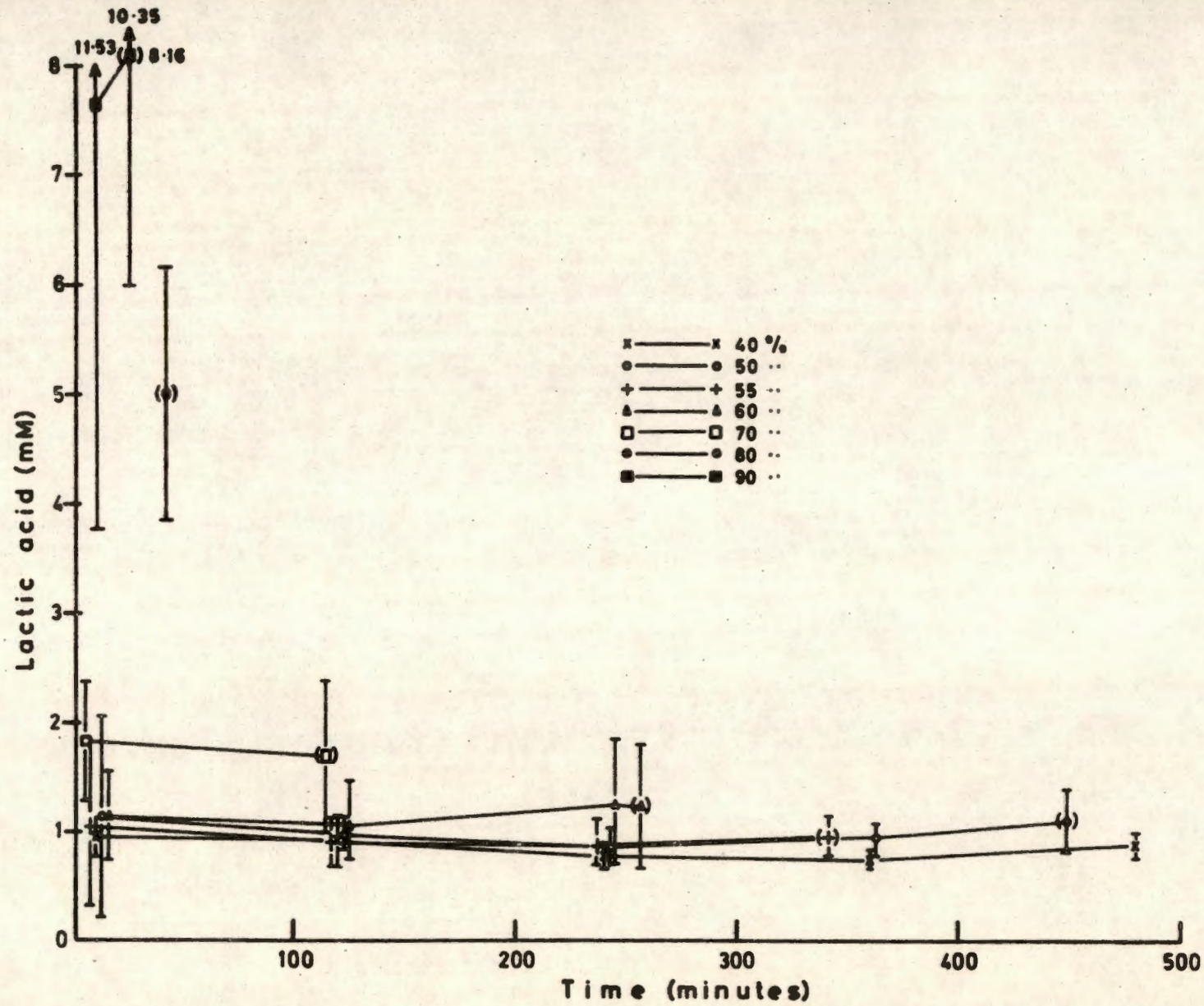

Fig. 8a Lactic acid relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

80 % { 9 min = 9·185
25 min = 10·647

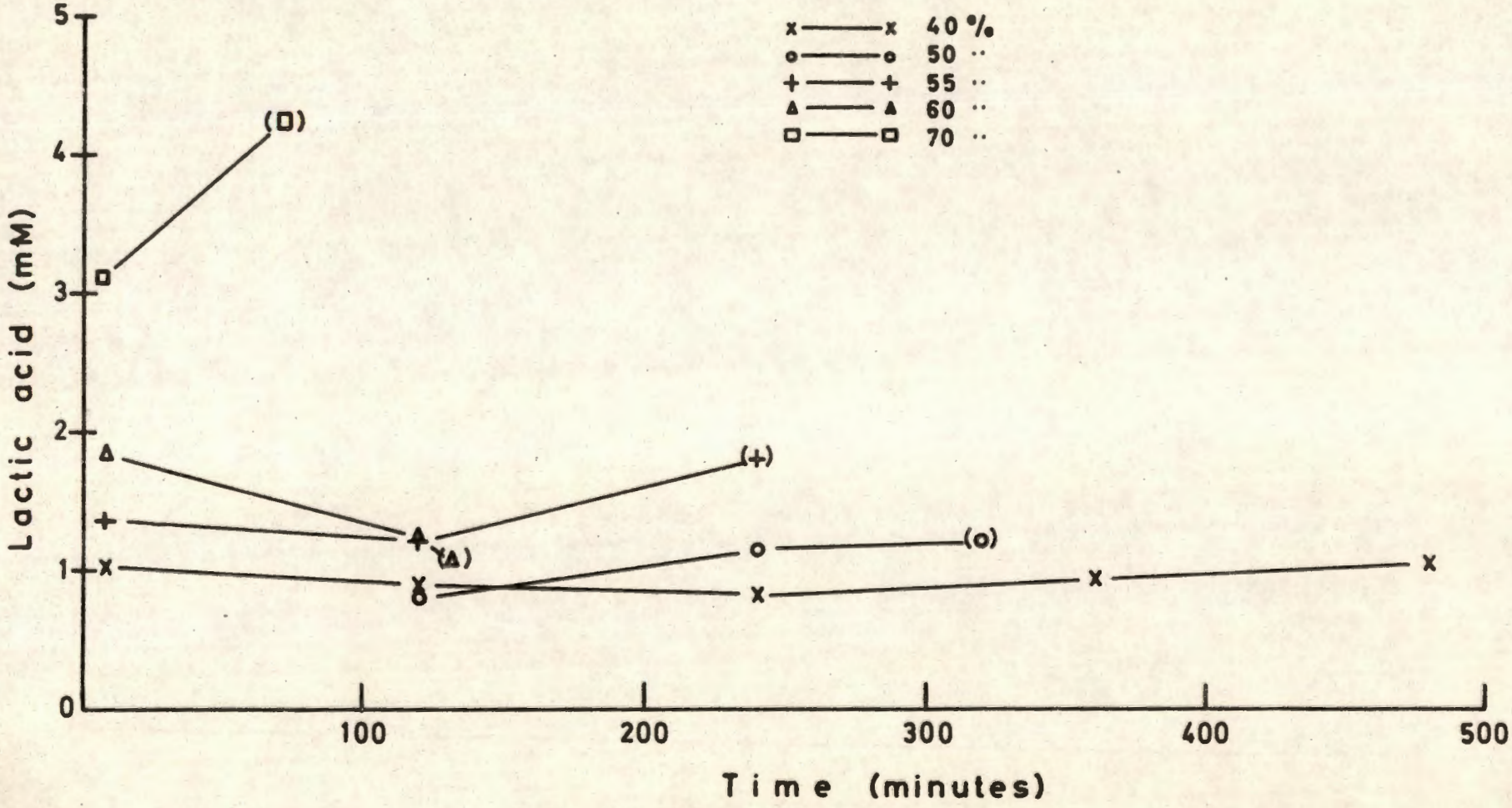

Fig. 8b Lactic acid relative to time at various levels of aerobic capacity. (Subject FR).

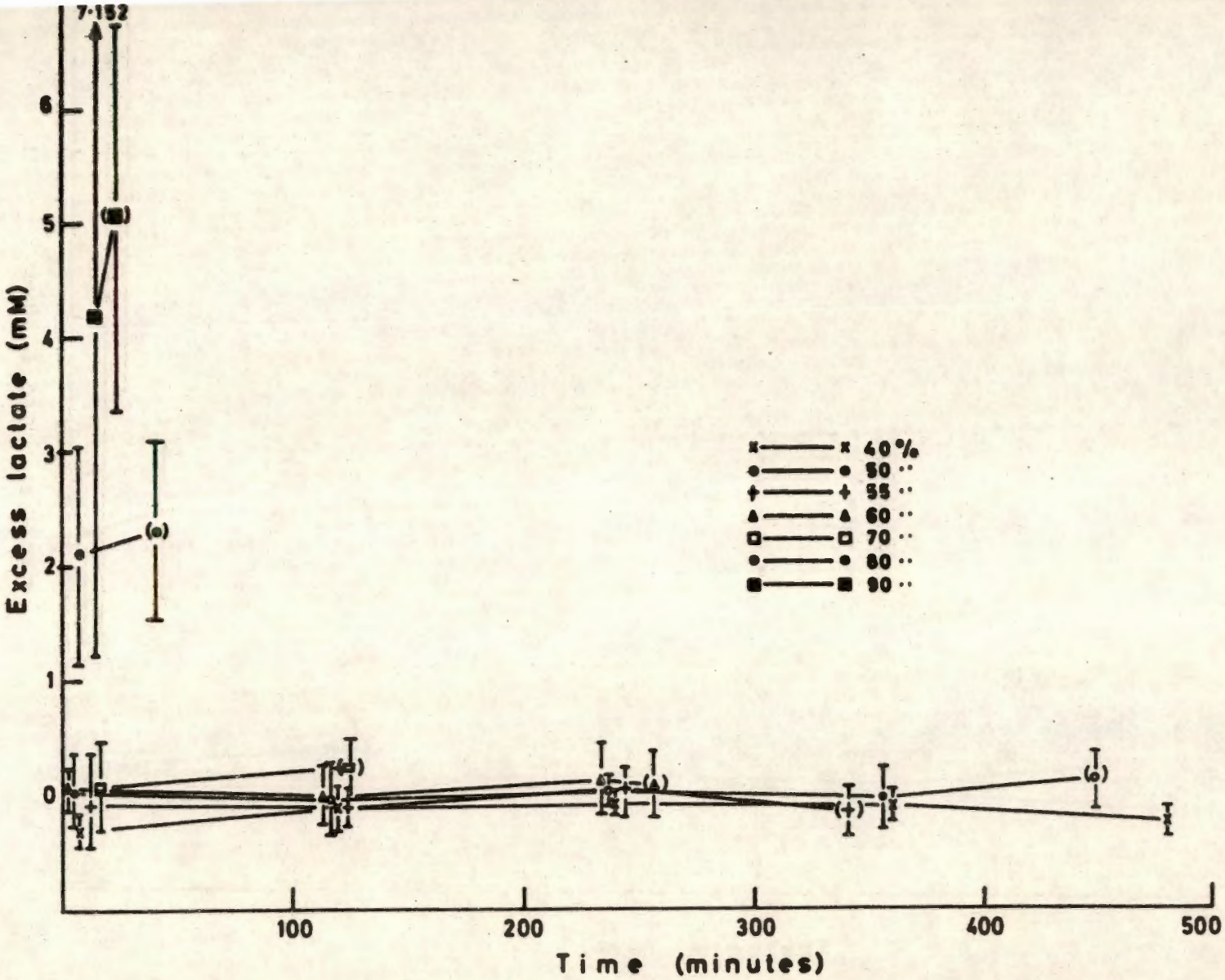

Fig. 9a Excess lactate relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

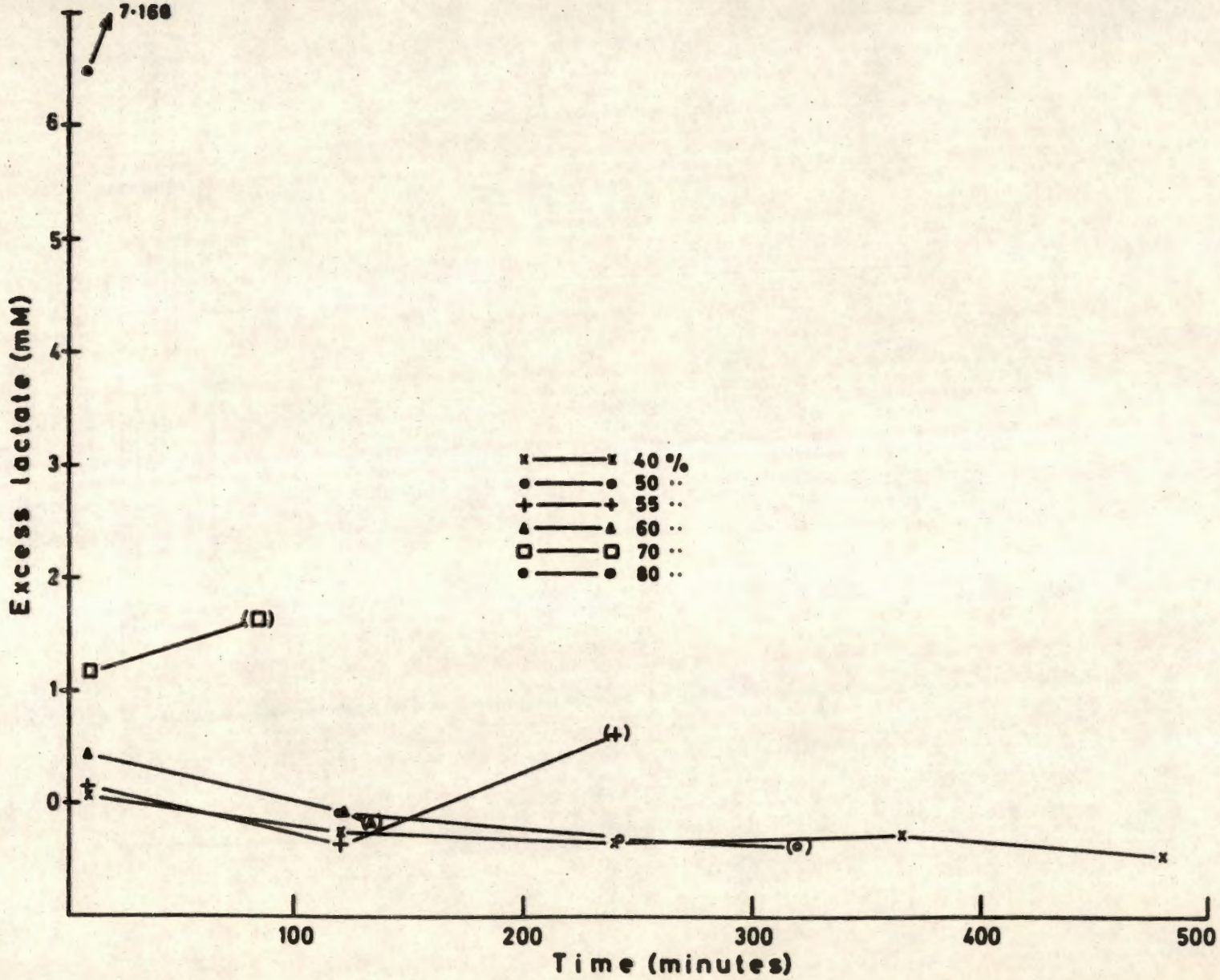

Fig. 9b Excess lactate relative to time at various levels of aerobic capacity. (Subject FR).

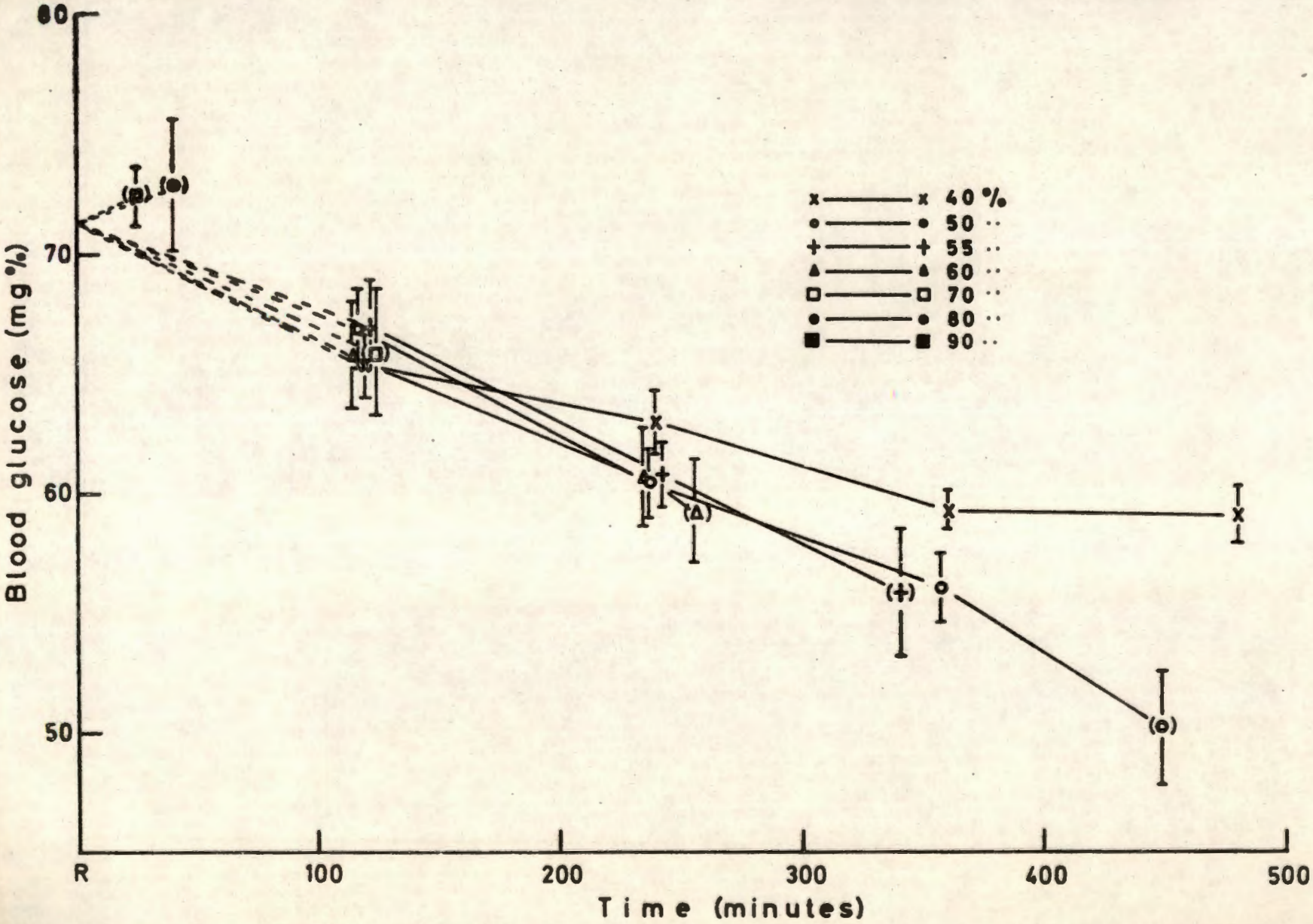

Fig. 10a Blood glucose relative to time at various levels of aerobic capacity. (Grouped data and 95% confidence limits).

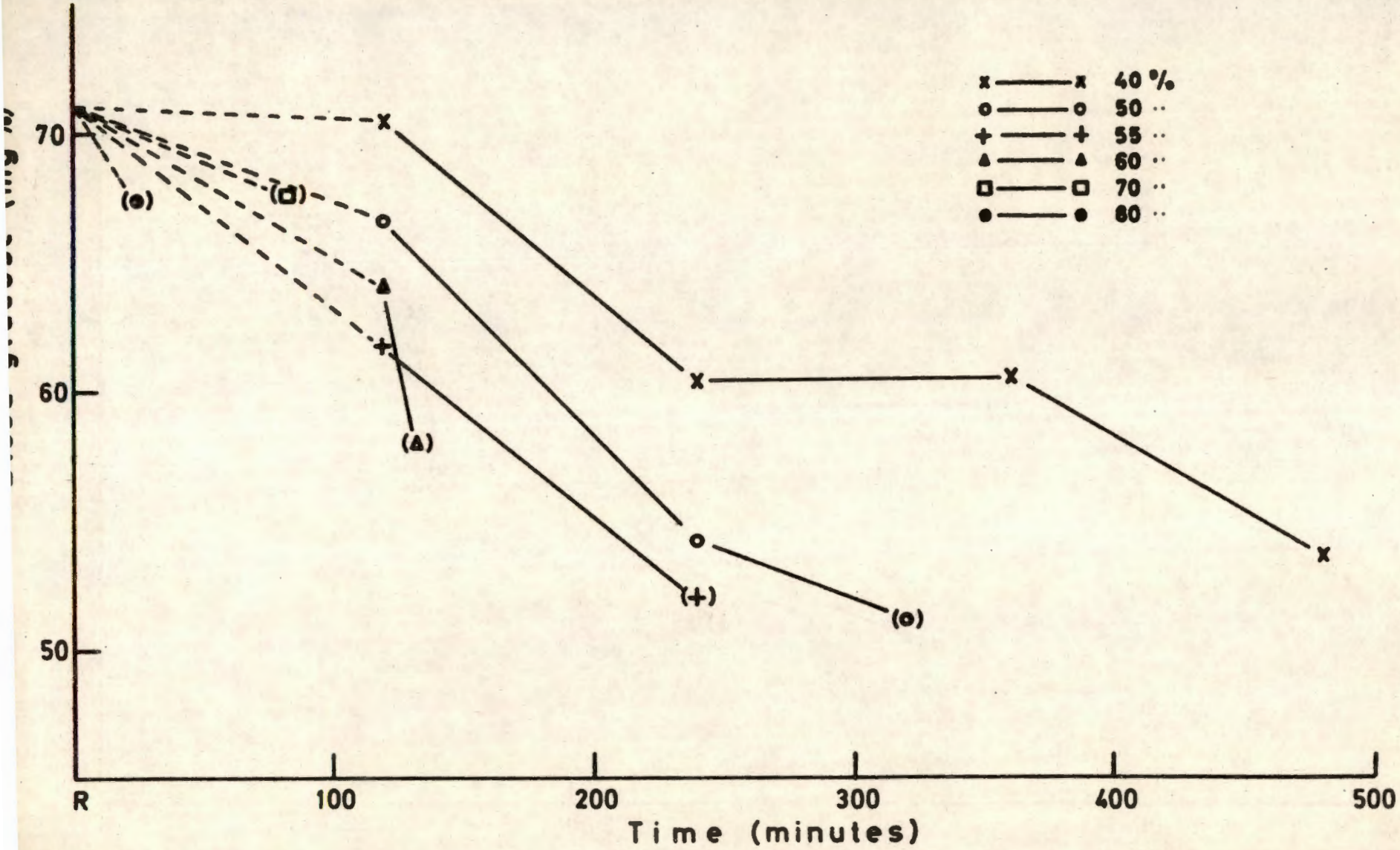

Fig. 10b Blood glucose relative to time at various levels of aerobic capacity. (Subject FR).

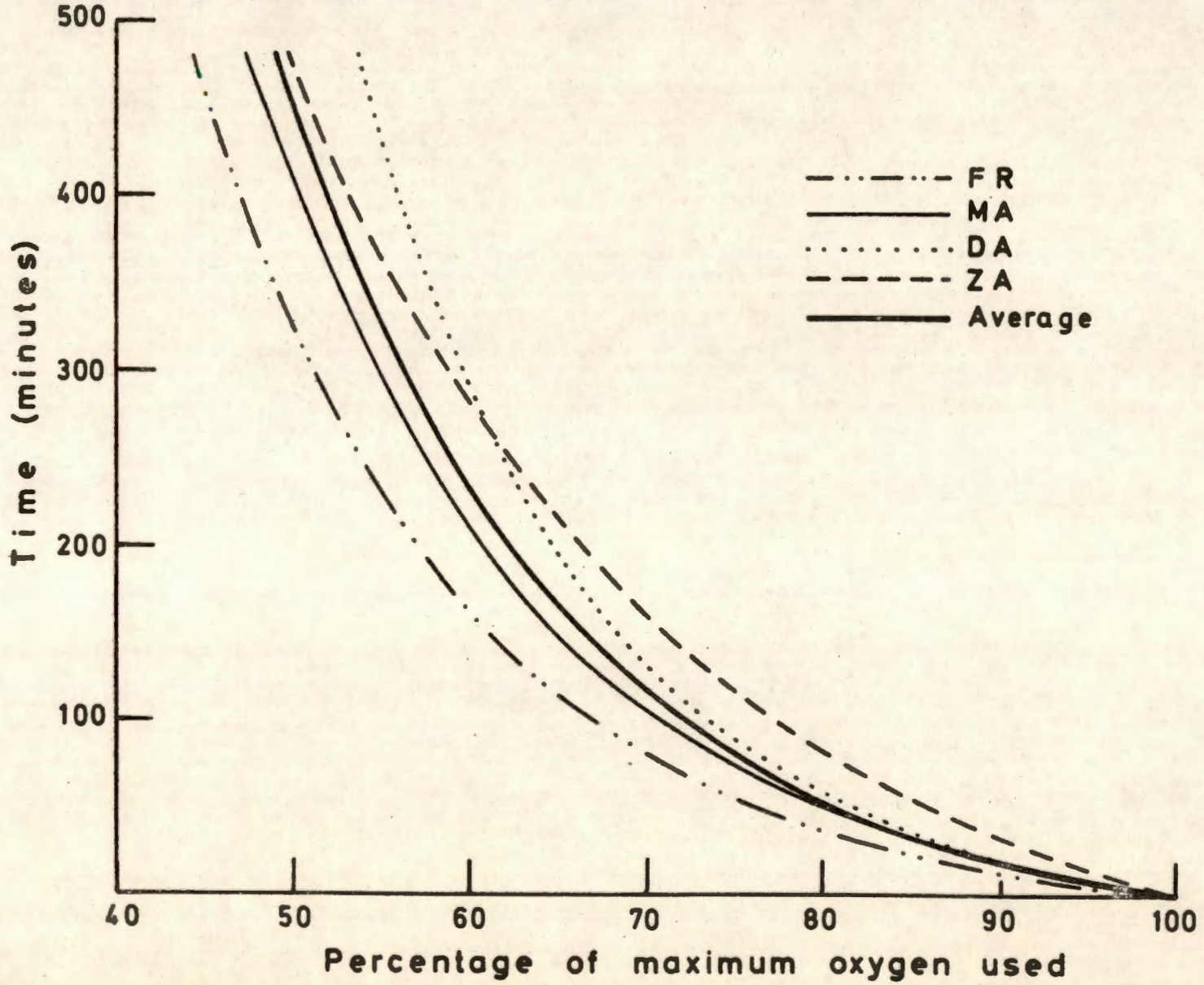

Fig. 11 Tolerance time of work at various levels of aerobic capacity.