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THE UNIVERSITY OF ALBERTA

THE ONSET OF METABOLIC ACIDOSIS AND THE OPTIMAL SPEEDS OF WALKING AND RUNNING

by

© William R. Dean

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ABSTRACT

The primary purpose of this study was to determine the onset of metabolic acidosis and determine the relationship to the optimal speeds of walking and running in terms of sex and fitness.

Forty volunteers of a variety of activity levels, 20 males and 20 females were subjected to three testing sessions. In session one, each subject walked and ran on a motor driven treadmill at several speeds which served to reduce anxiety associated with the treadmill. In session two, the optimal speeds of walking and running on a level treadmill were subjectively determined. In addition, the steady state oxygen consumption at these speeds were determined during a six minute test. The percentage body fat was estimated by the hydrostatic method at the conclusion of this session. In session three, the determination of maximal oxygen consumption and the onset of metabolic acidosis, represented by the minimum of the ventilatory equivalent for oxygen, was determined with the assistance of a Beckman Metabolic Measurement Cart. The data collected was subsequently used to divide the forty subjects into four groups based upon sex and fitness which was represented by their percentage of maximal oxygen consumption at the onset of metabolic acidosis.

The data of the four groups was subjected to statistical treatment of one and two-way analysis of variance. Significant measurements at

the 0.05 level of confidence were subjected to a Scheffe Test.

The results indicated that: (1) There was no significant difference in the selection of an optimal speed of walking, or the relative oxygen consumption at that speed, in males and females of high and low fitness groups. (2) There was a significant difference between high fit males and low fit females in the selection of an optimal speed of running. (3) The speed and relative oxygen consumption at the onset of metabolic acidosis was significantly higher in the high fitness groups than the low fitness groups. (4) The speed and relative oxygen consumption at the optimal speed of walking was significantly below the speed and relative oxygen consumption at the onset of metabolic acidosis. (5) The speed and relative oxygen consumption at the optimal speed of running was not significantly different from the speed and relative oxygen consumption at the onset of metabolic acidosis in the high fit males or high fit females. (6) The males' power output was significantly higher than the females' power output.

The proximity of optimal speeds of running and the onset of metabolic acidosis suggested that the most comfortable speed of running may be used as an effective training stimulus in high fit individuals only.

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CHAPTER 1

STATEMENT OF THE PROBLEM

Introduction

Clearly the concept of maximal oxgyen uptake ($\dot{V}O_2$ max) has received relatively general acceptance as the primary determinant of cardiorespiratory endurance capacity (23). However, individuals with similar maximal oxygen uptake values often performed quite dissimilar in an endurance event (16,56). Endurance athletes, as well, have continued to improve their performance in running events although maximal oxygen uptake had plateaued (87). These often reported findings suggest that measures other than maximal oxygen uptake, may be important determinants of endurance performance.

One such measure that had recently received a great deal of attention was the "Onset of Metabolic Acidosis" or "Anaerobic Threshold." Much of the initial research had been carried out by Wasserman (3,54, 71,72) who defined the anaerobic threshold as the oxygen consumption or the work intensity at which there was a significant increase in lactic acid within the muscle when compared to its resting level. Various other researchers analyzed the phenomenon under other titles, such as, the "Onset of Plasma Lactate Accumulation" (OPLA) (32), the "Aerobic Threshold" (41), and the "Threshold of Anaerobic Metabolism" ($\dot{V}$TAM) (69). The attractiveness of the measurement of this phenomenon was based upon: (a) Anaerobic Threshold (AT) values tend to be higher in endurance trained athletes compared to their sedentary counterparts

(21,44,60,77) or in other words, their onset of metabolic acidosis occurred at a larger fraction of $\dot{V}O_2$ max; (b) endurance athletes perform at some fraction of maximal oxygen consumption rather than max; (c) individuals with high anaerobic threshold values tend to show a greater glycogen sparing capacity (23,66); muscle glycogen depletion was a well recognized limitation to endurance performance (44,48,p.38).

It has been suggested that endurance athletes perform at an oxygen consumption or workload intensity just below the anaerobic threshold (32,40). Such a performance pace would delay significant increase in lactic acid which has been shown to be a primary metabolic factor associated with the onset of fatigue (2,p.77). A performance pace immediately below the onset of metabolic acidosis would optimize aerobic metabolism, and therefore, should enhance endurance performance. This should hold true regardless of the individual's level of training, optimal endurance pace would just proceed the onset of metabolic acidosis.

Anaerobic threshold studies have noted that the lower limit of the anaerobic threshold for leg exercise of normal individuals, appeared to correspond to an oxygen consumption needed by the typical adult to walk on the level at a normal speed (approximately 4.0 kilometres per hour) (16,73). This implied that minimal exposure to exercise, merely walking at a comfortable pace during daily tasks, was a level beyond which metabolic acidosis would have proceeded for these inactive individuals.

There appeared to be an optimal speed of walking for each individual at which the energy expenditure per unit distance travelled was minimum (5,6,13,58,84,87,88). Usually this optimal speed was the freely chosen, comfortable speed for an individual, based on optimal step frequency and stride length. Since optimal speeds of walking have been reported to be in the same range as speeds for the onset of metabolic acidosis for sedentary individuals, it may be that this chosen speed was metabolically most comfortable because it was immediately below the threshold for metabolic acidosis.

Several researchers have indirectly demonstrated that for subjects of higher cardiorespiratory endurance capacity ($\dot{V}O_2$ max of approximately 55 millilitres per kilogram per minute), the onset of metabolic acidosis was generally delayed to a higher intensity level, a treadmill speed between 12 and 14 kilometres per hour (41). Subjects with maximal oxygen consumptions of very large volumes (70 - 82 millilitres per kilogram per minute) exhibited a delayed onset of metabolic acidosis corresponding to treadmill speeds up to 17 or 18 kilometres per hour (16).

Like the optimal speed of walking, an optimal speed of running had been postulated to be that at which the energy expenditure was minimum per unit distance travelled (5,49,50,62). As in the case of walking, the freely chosen speed corresponded to the minimum energy expenditure speed, or optimal speed, due to an optimal stride length. Optimal running speed values in the literature have ranged from 7.8 to 11.1 kilometres per hour for normal, and moderately active individuals respectively (5,50,51). Perhaps this optimal speed of running was concommitant with a threshold level for an onset of lactate accumulation in the working muscles and blood.

Possibly the cardiorespiratory fitness level, as exemplified by the traditional $\dot{V}O_2$ max, or the oxygen consumption at the anaerobic threshold may demonstrate a positive relationship with either an optimal speed of walking or running. A high anaerobic threshold would imply a greater delaying ability for the onset of metabolic acidosis to higher work intensities and, therefore, possibly a closer relationship to an optimal speed of running. Or conversely, low cardiorespiratory fitness represented by a low anaerobic threshold, and faster onset of metabolic acidosis, might demonstrate a closer relationship to minimal physical activity or an optimal speed of walking.

The Problem

If it could be demonstrated that an individual's anaerobic threshold level was closely related to either his or her optimal speed of walking or running, then, this would help explain metabolically the choice as an optimal speed. Should the relationship of the onset of metabolic acidosis with an individual's optimal speed of walking or running prove to be substantially high, perhaps then, an estimate of anaerobic threshold values could be simplified to the determination of the subject's optimal speed of locomotion.

Free fatty acids were the dominant source of fuel for contracting muscles at low workloads (below the anaerobic threshold) (55). The optimal exercise intensity prescription for the reduction of excess adipose should, therefore, be at or near the individual's anaerobic threshold, since beta oxidation of fatty acid fuels is optimized. If the optimal speed of locomotion, whether walking or running was shown to be below an intensity that would initiate the onset of metabolic acidosis, then, these optimal speeds could also serve as accurate intensity levels for the prescription of exercise for adipose reduction.

Since the validity of the relative percent concept for equating training intensity based on the use of a percent of maximum heart rate as an indicator of percentage maximal oxygen consumption has been questioned (40), perhaps a better method for equating the training stimulus between subjects might be to equate individuals based on the onset of the anaerobic threshold. If it should result that a dependable relationship exists between the oxygen consumption at the anaerobic threshold and running speed (at zero percent grade), then running speed could be used as the equating variable (40).

The purpose of this study was to determine the onset of metabolic acidosis, in men and women, and examine its relationship to the optimal speeds of walking and running relative to varying fitness levels.

LIMITATIONS OF THE STUDY

(1) Variation in the calibration of the metabolic cart and the treadmill speed between [illegible]ng sessions.

(2) Walking and running speeds selected by each subject were in fact the optimal speed for that activity.

(3) All subjects were requested to avoid ingesting any food or nutrients for at least two hours prior to testing. The complete instructions to subjects are in Appendix B. The diet of subjects immediately prior to testing could have affected the metabolic cost of the activity measured due to the specific dynamic action of foodstuffs.

(4) All subjects were requested to avoid vigorous physical activity for at least two hours prior to testing. The physical activity of the subjects immediately prior to testing could have affected the metabolic cost of the activity measured.

(5) The onset of metabolic acidosis was in fact at the minimum level of the ventilatory equivalent for oxygen.

(6) Maximal oxygen consumption levels determined could be misleadingly low in the unfit subjects because of their inexperience with high levels of fitness stress.

DELIMITATIONS OF THE STUDY

(1) The study was delimited to the 20 female and 20 male volunteers that were sampled from the University of Alberta students.

(2) Comparisons between the optimal speeds of walking, running, the onset of metabolic acidosis, and maximal oxygen consumption in terms of fitness groups were based upon the percentage of maximal oxygen consumption at the onset of metabolic acidosis.

DEFINITIONS

(a) Walking: forward linear motion of the body accompanied by a period of double leg support in every step

(b) Running: forward linear motion of the body accompanied by a period of momentary suspension in the air during every step

(c) Optimal Speed: the speed of walking or running which the subject chose most naturally. This was supposedly the speed at which the energy expenditure was a minimum (5,49,50,58,89)

(d) Metabolic cost: or net energy expenditure is equal to the gross energy expenditure minus the resting or basal energy expenditure for an equivalent time period (58)

(e) Steady state: balance between the energy required by the working muscles and the rate of energy production via aerobic metabolism

(f) Onset of Metabolic Acidosis: the point of oxygen consumption or work intensity at which the curve for the ventilatory equivalent for oxygen was minimum (59). This technique accurately reflects a significant increase in blood lactate

(g) Anaerobic Threshold: a term synonymous with the "Onset of Metabolic Acidosis"

(h) Fitness: as representative of the percentage of maximal oxygen consumption corresponding to the onset of metabolic acidosis in each subject

HYPOTHESES

The following null hypotheses were tested for significance at the 0.05 level of probability:

Hypothesis 1

There is no significant difference between the speeds at optimal walking and at the onset of metabolic acidosis in males and females of high and low fitness.

Hypothesis 2

There is no significant difference between the speeds at optimal running and at the onset of metabolic acidosis in males and females of high and low fitness.

Hypothesis 3

There is no significant difference between the relative oxygen consumption at steady state optimal speed walking and the relative oxygen consumption at the onset of metabolic acidosis in males and females of high and low fitness.

Hypothesis 4

There is no significant difference between the relative oxygen consumption at steady state optimal speed running and the relative oxygen consumption at the onset of metabolic acidosis in males and females of high and low fitness.

Hypothesis 5

There is no significant difference in the proximity of the selection of the optimal speed of running and the onset of metabolic acidosis between the sexes and high and low fitness groups.

Hypothesis 6

There is no significant difference in the power output at maximal oxygen consumption between the sexes and high and low fitness groups.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The purpose of the review of related literature to follow was to bring to date the state of research on the topic of the onset of metabolic acidosis and piece together a case for its relationship with an optimal speed of locomotion, namely walking and running. Only those studies deemed most pertinent for either establishing or refuting such a relationship were selected. Collateral studies were also discussed when their findings were of significance to the present problem under study.

The topical sequence followed in this chapter on the literature relating to the foregoing questions was:

(1) The Concept of Anaerobic Threshold

(2) Detecting the Onset of Metabolic Acidosis via Gas Exchange Parameters

(3) An Analysis of an Optimal Speed of Walking

(4) An Analysis of an Optimal Speed of Running

(5) Sex Differences Related to the Metabolic Cost of Walking and Running

(6) The Onset of Metabolic Acidosis, Endurance Performance, and an Optimum Pace

(7) Optimal Speeds of Walking and Running and the Speeds Associated with the Onset of Metabolic Acidosis

(8) Summary and Critique of Literature

THE CONCEPT OF ANAEROBIC THRESHOLD

If dynamic exercise begins at a very low intensity, such as zero watts on a bicycle ergometer, or the lowest speed of a motor driven treadmill, the ventilatory and circulatory systems begin to respond to the above resting value energy demands of the exercising muscle and correspondingly the oxygen consumption increases. At the onset of low intensities of exercise this initially elevated oxygen consumption acts in concert with stored phosphogens and oxymyoglobin to meet the initial demands of the exercising muscle. This energy is provided almost exclusively from the high energy phosphates, adenosine triphosphate (ATP) and creative phosphate (CP), via the alactic system within the specific muscles and activated with exercise.

With increasing levels of low intensity exercise, a greater amount of oxygen was extracted by the tissues resulting in more carbon dioxide being produced and expired. After the first few minutes of exercise, of low intensity, increasing amounts of free fatty acids were released into the circulation and transported to the working muscles and became the dominant source of fuel for contracting muscle at low workloads (55). Since little or no blood lactate was formed and values of 0.70 to 0.80 for the respiratory quotient were found during this low intensity exercise there was little doubt that this initial phase of dynamic progressive exercise primarily involved aerobic metabolism (66).

This increased availability and utilization of free fatty acids has been reported to have an inhibitory effect on glycolysis by production of citrate, an accumulation of which, inhibits pyruvate oxidation of glycolysis (4,25). If there was indeed glycolytic inhibition by free fatty acid metabolism, there should have been little lactate produced, and any that was, should have been oxidized to pyruvate due to the H-lactate dehydrogenase (H-LDH) isoenzyme pattern of the preferentially recruited slow twitch fibres (Type I) during low intensity exercise (41,65).

As the intensity increased more muscle fibres, Type I and possibly some Type II (fast twitch) were recruited. This produced a greater need for, and utilization of, ATP and correspondingly an increase in the concentration of adenosine diphosphate (ADP), adenosine monophosphate (AMP), and free phosphate ions (Pi). An accumulation of these metabolites released the inhibitory effect of citrate on phosphofructokinase (PFK), the rate-limiting enzyme in glycolysis (78), enhancing carbohydrate glycolysis and increasing the production of pyruvate (55).

Since free fatty acid oxidation was likely still high, some inhibition of pyruvate oxidation would still be present. As a result there would be an imbalance between pyruvate production and pyruvate oxidation, with some of the pyruvate being reduced to lactate (40,41, 70,76). A slight rise in blood lactate to about 2 millimoles per litre of blood was detectable at this point, and thus, appeared to be due to excess pyruvate and not, to the hypoxia of anaerobic metabolism, since mitochondrial nicotinamide dinucleotide (NAD) levels indicated adequate oxygenation (66).

Exercise intensities beyond this threshold that illicited an initial rise in blood lactate above resting levels, necessitated even greater recruitment of Type II muscle fibres, and an increased demand for ATP that could no longer be met almost entirely through aerobic metabolism. In order to continue exercising at the same intensity, ATP production must have been increasingly channeled through anaerobic metabolic pathways. Anaerobic glycolysis resulted in energy production of a very high rate to maintain performance, but, since the oxygen supply cannot meet the high demand, excess pyruvate was converted to lactate to regenerate reduced nicotinamide dinucleotide (NAD^+) so that glycolysis could continue.

The increased production of lactate, as a result of workloads of increasing intensity, eventually limited further work and muscular fatigue and exhaustion ultimately resulted.

The oxygen consumption or work intensity at which there was a significant increase in lactic acid within the muscle when compared to its resting levels, has been termed the "Anaerobic Threshold" (54). Since it has been reliably shown that the initial production of lactate during dynamic exercise was not a function of increased anaerobic glycolysis creating muscle hypoxia, but rather, an imbalance between the rate of pyruvate production and its rate of utilization via the citric acid cycle (40,41,70,76), the term anaerobic threshold was misleading. This phenomenon has been alternately termed by Weltman et al. (76) as the "Onset of Metabolic Acidosis", while Kinderman et al. (41) have suggested the "Aerobic Threshold" as a suitable replacement. Several German research groups (41,45) have deemed the term "anaerobic threshold" more appropriate to the sharp rise in lactate from a level of about 4 millimoles per litre of blood, a decrease in the fractional expiration of carbon dioxide ($\bar{F}ECO_2$), and a marked hyperventilation (41). They see this level as a transition to the predominance of anaerobic metabolism utilizing carbohydrate fuel.

To maintain consistency only the term "onset of metabolic acidosis" (formerly the anaerobic threshold) was used to describe the workload or the oxygen consumption just below which there was a non-linear increase in the carbon dioxide production, respiratory exchange ratio, and ventilation volume plus a rise in blood lactate to approximately 2 millimoles per litre of blood during an incremental work test (76,77). It should be noted that the above changes in the gas exchange parameters were transient and occurred only while lactic acid concentration was increasing and the bicarbonate concentration was decreasing.

DETECTING THE ONSET OF METABOLIC ACIDOSIS VIA GAS EXCHANGE PARAMETERS

In some way ventilation rate must be geared to metabolic demands. If ventilation was not adequate, the high rate of carbon dioxide production would result in severe acidosis with associated disturbances in cell function. On the other hand, if ventilation increased out of proportion to metabolism, alkalosis would result.

Naimark et al. (54) and Wasserman et al. (72) demonstrated that the point at which lactic acid was beginning to accumulate within the muscle could be reflected by several changes in gas exchange parameters. The most commonly utilized parameters of gas exchange have been non-linear increases in minute ventilation, expired carbon dioxide, and the respiratory exchange ratio. The introduction of reliable rapidly responding oxygen analyzers and on-line computer processing have enabled the computation and visualization of the onset of metabolic acidosis as it occurred during a performance test (3,73). Other ventilatory approaches to the measurement of the onset of metabolic acidosis included a decrease in end-tidal oxygen ($PETO_2$) tension without a concomitant change in end-tidal carbon dioxide ($PETCO_2$) tension (73) or the detection of an increased fraction of expired oxygen (FEO_2) (22). Each of these were manifestations of a non-linear rise in minute ventilation (VE) (22,73).

In comparison with invasive methods which provide considerable discomfort to subjects, the detection of the onset of metabolic acidosis via gas exchange parameters is virtually painless. The more painful of the invasive methods is the measurement of muscle lactate from biopsy specimens taken repeatedly during exercise for comparison with resting levels (65). A second more common invasive method, involves repeated blood sampling for the detection of changes in blood lactate concentration, bicarbonate concentration, and pH. The onset of metabolic acidosis being represented by an increase in bicarbonate concentration and a drop in pH (15,16,21,32,60).

The non-invasive analysis of the course of the ventilatory equivalent, with progressive intensity exercise, was a recent measure of the onset of metabolic acidosis (23,24,59). The ventilation equivalent has been defined by the ratio of minute ventilation to oxygen consumption (VE/VO_2) or VEO_2 which was an index for the economics of breathing in relation to oxygen uptake (59). An increase of the ventilatory equivalent of oxygen from its minimum was always the result of a hyperventilation with respect to oxygen uptake and represented the onset of metabolic acidosis (59). A systematic increase in the ventilatory equivalent for oxygen without an increase in the ventilatory equivalent for carbon dioxide was a qualified method to recognize a hyperventilation due to metabolic acidosis.

The validity of detecting the onset of metabolic acidosis via gas exchange parameters has been extensively studied utilizing changes in blood parameters as a criterion measurement for evaluation. Naimark et al. (54) compared the changes in the respiratory exchange ratio with changes in arterial plasma bicarbonate concentration through regressional analysis and obtained a correlation coefficient of r = 0.98 which was highly significant. Similarly, Davis et al. (22) obtained a significant regression coefficient of r = 0.95 when the onset of metabolic acidosis, determined by an abrupt increase in venous lactate (to approximately 2 mmol/litre) was plotted versus non-linear increases in minute ventilation, expired carbon dioxide, and the respiratory exchange ratio. Of the three gas exchange parameters, the best single measure for detecting the onset of metabolic acidosis was minute ventilation while the least specific was the respiratory exchange ratio. The inaccuracies associated with the use of the respiratory exchange ratio (R) as an indicator of the onset of metabolic acidosis are well established (15,71,72,75), therefore it is seldom used singularly.

The validity of the use of the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$) in particular has been examined by several investigators (23, 59,74). Reinhard et al. (59) reported a correlation coefficient of r = 0.94 between the determination of the onset of metabolic acidosis by means of computer assisted on-line ergospirometry for $\dot{V}E/\dot{V}O_2$ and capillary lactate and blood gas analysis at one minute intervals during an incremental exercise test. Although other investigators have utilized the ventilatory equivalent for oxygen in contrast with blood lactate measurements, they have not reported the correlation found between these measures. They did however report that the determination of the onset of metabolic acidosis via the minimum of $\dot{V}E/\dot{V}O_2$ of an incremental, dynamic, exercise test was "both an established criteria and valid method" (24,43,74).

Several investigators have examined the reliability of detecting the onset of metablic acidosis using gas exchange parameters with test-retest protocols. Early researchers (54,72) reported that the gas exchange measures were highly reproducible by test-retest procedures although no values were given for the correlation coefficients. Later research, Davis et al. (22) obtained reliability coefficients of r = 0.77, r = 0.74, and r = 0.72 for detecting the onset of metabolic acidosis via gas exchange parameters during arm cranking, leg cycling and treadmill walking respectively. Although statistically significant, they were only moderately high correlations. The investigators provided the explanation in that: (a) there were non-linear increases in oxygen consumption for some of the work rate increments which occurred most frequently during treadmill walking, likely due to a mechanical inefficiency at particular speeds and grades and (b) a possible release of lactate momentarily as the work rate was being increased, particularly as the exercise intensity approached the threshold value. Together these factors may have been attributable to the spurious estimates of the onset of metabolic acidosis.

In a further study by Davis et al. (23) utilizing the ventilatory equivalent for oxygen to detect the onset of metabolic acidosis, reliability coefficients of r = 0.91 were obtained both prior to and following nine weeks of training to alter the threshold levels.

In summary, from the discussion above, it was apparent that the detection of the onset of metabolic acidosis using gas exchange parameters in general, and the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$) in particular, was both valid and reliable.

AN ANALYSIS OF AN OPTIMAL SPEED OF WALKING

The relationship between the speed of walking and its metabolic cost have been generally viewed as curvilinear (5,6,13,17,29,58,84,87, 88) though consensus did not entirely exist (8,26,31,51). Of those researchers that have described the relationship as curvilinear each had derived a unique regression equation for predicting the net metabolic cost of walking as well as a unique optimal speed. In general, a hyperbolic curve was produced with the net energy expenditure per unit distance travelled plotted against the speed of walking, thus indicating that, there existed an optimal speed at which the energy expenditure per unit distance travelled was minimum.

Ralston (58) and more recently Bhambhani (5) and Zarrugh and Radcliffe (88) have demonstrated that the optimal speed of walking varied between individuals. The optimal speed was usually at or near the speed which the subject chose 'naturally' or which he or she subjectively regarded as 'most comfortable.' The actual optimal speeds that have been presented in the literature have varied from approximately 65 metres per minute to 85 metres per minute or 3.9 to 5.1 kilometres per hour (5).

AN ANALYSIS OF AN OPTIMAL SPEED OF RUNNING

Although research analyzing the relationship between the metabolic cost and speed of running have tended to describe the relationship as linear (11,13,31,45,49,51,63,86) additional research have described the relationship as curvilinear (34,42,61).

Recent research studies indicated that the relationship between the metabolic cost and speed of running was relatively linear, as most recent researchers advocated, this implied that an optimal running speed based on a speed of minimum energy expenditure could not have existed. However, Mayhew (49) claimed that there was an optimal speed of running at which the energy expended per unit distance travelled was minimum. When the energy cost per kilogram body weight per kilometre of distance run was plotted against running speeds between 8 kilometres per hour and 18 kilometres per hour two regressional lines that intersected at a speed of 11.1 kilometres per hour (185 metres per minute) resulted, which he claimed was the optimal running speed. A later study by the same investigator (50) compared the oxygen cost and energy requirement of running in trained and untrained males and females found that the difference in energy cost between trained and untrained groups of each sex was least at 180 metres per minute.

Both Hogberg (38) and Knuttgen (42) demonstrated that for each running speed, there was a step length at which the energy expenditure was minimum. This optimal step length varied between individuals and was usually the one which the subject chose most 'freely or naturally.' Since running speed is given by the product of the step length and step rate or frequency, it is, therefore, not surprising that Mayhew (50,51) and others (5,62) have suggested an optimal speed. Elliot et al. (28) examined the freely chosen stride length and stride rate changes while running on a treadmill at four graded velocities and found that the adoption of an optimal rate and length of stride may be crucial in increasing recreational running efficiency.

SEX DIFFERENCES RELATED TO THE METABOLIC COST OF WALKING AND RUNNING

Previous studies have tended to detect no statistical difference between the sexes in the gross metabolic cost of walking (27,58,87). Blessy et al. (6) and Bhambhani (5) were unable to detect any difference in either the gross or the net metabolic cost of walking. The net cost being determined by the subtraction of the energy cost of mere standing from the gross energy cost of walking. Contrary findings leaned towards a slightly greater gross energy expenditure by males when walking a unit distance (10, 35).

Falls and Humphrey (31) were unable to detect any real difference between the sexes in the net metabolic cost of both walking and running. Howley and Glover (39) as well as Brandsford and Howley (11) presented a third option, that the metabolic cost of walking and running a unit distance was greater in females than males. Both research groups found that the sexual differences in net metabolic cost was more accentuated while running. Bhambhani (5) demonstrated a similar greater gross and net metabolic cost in females than in males running a unit distance.

The greater average relative body fatness (percent fat) of females compared with males has been mentioned as one factor responsible for the sex difference in running performance. Excess body fatness decreased performance in relatively prolonged, weight bearing work such as distance running by increasing the body weight and, therefore, the energy required to perform any given level of work without contributing to the body's energy producing capacity. The consequence being, maximal oxygen consumption was elicited at a lower rate of work, and the pace that could be maintained for a given period of time was reduced (19).

Cureton et al. (19) attempted to directly study and quantify the extent to which the difference in performance between men and women in distance running was related to the sex difference in percent fat.

Based on data from normal male and female college students it was estimated that approximately 25 percent of the mean sex difference in performance on a 12-minute run was related to the mean sex difference in percent fat.

A later study, also headed by Cureton (20), used the addition of external weight to the bodies of males, to investigate the extent to which differences between adult male and female runners, in distance running performance, and metabolic responses to running, were due to the sex differences in excess body weight. Equating the percentage of excess body weight of the groups of male and female runners reduced the sex difference in treadmill run time and 12-minute run performance by approximately 30 percent. The primary metabolic consequence of the greater sex-specific percentage of fat of women was to increase the energy required to run at any given speed, without contributing to their energy-producing capacity (20). Running at any given submaximal speed, therefore, required a greater percentage of the maximal oxygen consumption of women and produced greater physiological stress.

THE ONSET OF METABOLIC ACIDOSIS, ENDURANCE AND AN OPTIMUM PACE

It had become apparent that the level of an athlete's onset of metabolic acidosis was a very critical factor in determining his potential for prolonged physical exercise. It was also evident, from a limited number of studies, that the onset level could be elevated through training (23,36) and that successful long-distance athletes have significantly higher onset of metabolic acidosis levels than did normal individuals (16,32,69). The onset of metabolic acidosis occurred at approximately 45-55 percent of maximal oxygen consumption in the untrained subject (22,23,40,59,73,76,77), at approximately 60-75 percent in the physically active non-endurance athlete (37,53) and in some instances, in excess of 85 percent of VO_2 max in the highly trained endurance athlete (16,32,60,69).

The relationship between maximal oxygen uptake and the onset of metabolic acidosis has been evaluated by several researchers. A positive relationship was well established, but, correlation coefficients have ranged widely ($r = 0.52$ to $r = 0.85$) (20,77). Although individuals who had a high maximal oxygen uptake value would likely have had a later onset of metabolic acidosis relative to a percentage of their maximum oxygen uptake, this relationship was only fair (76). This in part could have explained the finding that individuals with similar maximal oxygen consumption performed quite differently during an endurance event (16).

The indiscriminate use of the maximal oxygen consumption concept in previous research has been questioned (40). The effects of physical training are probably evident in subtle internal cellular adaptations which may or may not be manifested in gross changes in the VO_2 max. In this respect, since the onset of metabolic acidosis is likely a reflection of intracellular activity, the onset of metabolic acidosis may be viewed as a valid criterion variable with which to compare improvements through training (40).

Weltman et al. (76) evaluated the use of the onset of metabolic acidosis as compared with VO_2 max when evaluating metabolic responses to submaximum exercise. Through the analysis of both submaximum and maximum exercise responses of 33 females, it was concluded that while VO_2 max was an accepted criterion for maximum cardiorespiratory fitness, and did provide some information about submaximum fitness levels, it was suggested that, regardless of an individual's VO_2 max, the onset of metabolic acidosis may also be used when evaluating submaximum fitness.

Several studies have attempted to determine the contribution of maximal oxygen uptake, running economy, and lactic acid accumulation to distance running success. Costill et al. (16) analyzed the responses of 16 highly trained runners by venous blood sampling immediately after

10 minute submaximal runs on the treadmill at 214, 241, or 268 metres per minute. They found that lactic acid accumulation was directly proportional to their initial fitness rankings based upon their previous best 10 mile times. Each subject crossed their threshold for the onset of metabolic acidosis, if 2 mmol/litre of lactate per litre is used as the threshold (41,66), in the same order of initial fitness ranking.

Farrel et al. (32) analyzed the idea that runners set a race pace which closely approximated the running velocity at which lactate began to accumulate in the plasma by studying the metabolic data of 18 male, experience distance athletes. A series of eight, 10 minute steady state runs, were performed on a treadmill, at speeds between 214 and 322 metres per minute, with venous blood sampled within 30 seconds of each run. Maximal oxygen uptake was also determined on two separate occasions. The onset of plasma lactate accumulation (OPLA) was defined as an accumulation of lactate, which had increased to that concentration, which overcame the gradient between muscle and blood, rather than the onset of anaerobic metabolism (32). All subjects, in addition to the submaximum treadmill runs, were compared at actual race performance distances of 3.2, 9.7, 15, and 19.3 kilometres, and thirteen of the subjects at the marathon distance. It was found that the strongest relationship between any single variable that was measured, and the actual race performance data, was that of the treadmill velocity corresponding to the onset of plasma lactate accumulation. This relationship existed at all race distances and showed correlation coefficients equal to, or in excess of r = 0.91. The mean difference between the treadmill velocity corresponding to the OPLA and the marathon pace was a mere 8 ± 5.3 metres per minute. It seemed that, regardless of the competitive level, the highly trained endurance athlete could maintain an average velocity during a marathon which was only slightly above his OPLA velocity (32).

Daniels et al. (21) analyzed the lactate accumulation in runners and non-runners during steady state exercise at a predetermined work-load just above the onset of metabolic acidosis. They found that, not only had training delayed the onset of blood lactate accumulation, as a function of exercise intensity, but it had also accounted for the decrease in the initially elevated blood lactate that had occurred during steady state exercise at these workloads. This led them to suggest that the accumulation of venous lactate was to some extent reversible during steady state exercise in the trained individual.

The contribution of the onset of metabolic acidosis and maximal oxygen consumption in cross country skiers has also been studied. Rusko et al. (60) attempted to investigate these parameters as well as the contribution of muscle enzymes and fibre compositions in young female skiers. The onset of metabolic acidosis was determined both by blood lactate samples and a departure from linearity in the V_E and CO_2 responses. Muscle biopsy of the medial vastus lateralis was used to classify slow and fast twitch fibres and the enzymes; succinate dehydrogenase (SDH), malate dehydrogenase (MDH), citrate synthase (CS), and lactate dehydrogenase (LDH). The onset of metabolic acidosis occurred at approximately 85 percent of maximal oxygen consumption in these fifteen highly trained young skiers. Muscle biopsy analysis determined a 60 percent slow twitch nature of the fibres sampled from the medial vastus lateralis. The percentage of slow twitch fibres, however, showed no significant correlation with the skiers' maximal oxygen uptake values or the onset of metabolic acidosis, whether expressed as a percentage of maximal oxygen uptake or as absolute litres of oxygen consumed. Of the enzymes examined, both the activities of succinate dehydrogenase, and citrate synthase correlated significantly with the onset of metabolic acidosis. The results obtained seemed to support the hypothesis that, the submaximum or prolonged work capacity near the onset of metabolic acidosis might have been related to the oxidative capacity of the muscles, whereas, the maximal oxygen consumption might more likely have been related to central or local factors of circulation (60). Low lactate dehydrogenase activity was associated with a greater delayed onset of metabolic acidosis in these subjects which may indicate that, the ability to keep the blood lactate concentration at a low level might also have been related to the capacity of the muscles to produce lactate.

Contrary to the results of Rusko (60), Green et al. (37) found no significant correlation between fibre type distributions of ten active college males and the onset of metabolic acidosis. Neither did they find a statistically significant correlation between succinate dehydrogenase enzymatic activity and the onset of metabolic acidosis.

The claim that long distance athletes set a race pace which closely approximated an intensity near that which would onset metabolic acidosis appeared reasonably well substantiated (16,32,60,69). However, analysis of endurance performances of shorter duration, such as those of middle distance runners, and the significance of the onset of metabolic acidosis in the outcome, was limited. Ariyoshi et al. (1) attempted to examined the physiological basis of the gradual decrease of speed pattern of pacing of many middle distance athletes. From the physiological point of view, it would have seemed that the most logical tactic of pacing for a middle distance competitor would have been the adoption of a relatively uniform pace throughout most of the race; this would correspond to the fraction of the maximal oxygen consumption realizable without lactate accumulation, and anaerobic activity would be reserved for the final sprint as the finishing tape was approached.

Contrary to this model view, the results of eight male middle distance runners demonstrated that a gradual decrease of speed pattern of pacing used appreciably less total oxygen than a steady or a gradual increase of speed pattern of running for a distance of 1400 metres in 4 minutes (1). While it made empirical sense to operate at a fixed percentage of maximal load throughout a race, such a concept must allow for the possibility of "drift" in physiological limits associated with fatigue, and if a runner was to maintain a constant level of body stress, he must of necessity make a gradual reduction of running speed (1). In other words, in order to maintain a steady physiological pace it may have been necessary to reduce the pace.

OPTIMAL SPEEDS OF WALKING AND RUNNING AND THE SPEEDS ASSOCIATED WITH THE ONSET OF METABOLIC ACIDOSIS

The optimal speeds of walking that have been generated by numerous researchers (5,6,13,29,58,84,87,88) have varied from approximately 65 metres per minute to 85 metres per minute or 3.9 to 5.1 kilometres per hour. The optimal speed of walking being that speed at which the energy expenditure per unit distance travelled was minimum. This speed was usually the most comfortable speed for a subject due to an optimal step frequency.

The lower limit for normal individuals of either sex, and all age groups tested, for the onset of metabolic acidosis appeared to be the same (22,73). This lower limit was equivalent to an oxygen consumption of approximately 1.0 litre per minute, the oxygen uptake needed by the typical adult to walk at a normal speed (4.0 kilometres per hour) on the level (73). In other words, an exercise intensity beyond a comfortable walk, for these least active individuals, would have crossed the threshold for the onset of metabolic acidosis. Wasserman et al. (71) also reported that patients with functionally significant heart disease could not exercise to the level of oxygen uptake necessary for walking at a moderate pace without developing a metabolic acidosis.

The optimal speed of running, primarily advocated by Mayhew (50,51), has been localized near 185 metres per minute or 11.1 kilometres per hour for both sexes. Bhambhani (5) found that the most comfortable running speeds chosen varied between 130 and 181 metres per minute for male and female university students.

The speeds that corresponded to an onset of metabolic acidosis have varied in relation to aerobic training levels. Kinderman et al. (41) demonstrated that cross country ski subjects, of moderately high cardiorespiratory endurance capacity ($\dot{V}O_2$ max of approximately 55 ml/kg/min) delayed the onset of metabolic acidosis corresponding to treadmill velocities between 12 to 14 kilometres per minute, with the grade of the treadmill at 5 degrees. Volkov et al. (69) determined the running speed corresponding to the "threshold of anaerobic metabolism" characterized by an abrupt increase in arterial blood lactate above resting levels. Subjects that had trained at different intensities and frequencies, similarly, exhibited considerable differences in the speed necessary to initiate lactic acidosis. These critical speeds varied from 156 to 204 metres per minute or 9.4 to 12.3 kilometres per hour for these experienced middle distance runners. Highly trained endurance athletes, such as the sixteen competitive runners studied by Costill et al. (16), exhibited maximal oxygen uptakes of very large volumes (70 to 82 ml/kg/min), delayed the onset of metabolic acidosis up to treadmill speeds of 300 metres per minute or 18 kilometres per hour.

Several studies have noted that the exercise intensity level associated with the onset of metabolic acidosis was a highly effective predictor of athletic performance time for endurance events (16,32). Katch et al. (40) as well as other researchers (41,44,66), have stated that theoretically training at intensities below or above the onset of metabolic acidosis should result in different physiological changes. Intensities below this level should see fat as the primary fuel substrate, and above this level would develop greater changes in cardiorespiratory parameters. These postulates were in agreement with the view of Kinderman et al. (41) who advocated that workload intensities necessary to reach the onset of metabolic acidosis are usually sufficient for physicial activity in prevention and rehabilitation, but in many cases high intensities are required for endurance training of athletes.

SUMMARY AND CRITIQUE OF LITERATURE

The onset of metabolic acidosis has been defined as the oxygen consumption, or work intensity, at which there was a significant increase in lactic acid within the muscle, when compared to its resting levels. Since it has been reliably shown that this phenomenon was not a function of increased anaerobic glycolysis creating muscle hypoxia (40,70), but rather an imbalance between the rate of pyruvate production, and its rate of utilization via the citric acid cycle, the initial description as an "anaerobic threshold" (55) or "threshold of anaerobic metabolism" (69) was inappropriate. The validity and reliability of detecting this onset of metabolic acidosis via gas exchange parameters was not clarified by many of the early reports since stringent statistical analyses were not applied, however, numerous recent researchers have clearly substantiated these methods. One of the important drawbacks of the present state of literature has been that no standard protocol has been devised for detecting the onset of metabolic acidosis via gas exchange measures, either on the treadmill, or the bicycle ergometer. It may have been that the various test protocols, used in a variety of studies, may have in themselves affected the accuracy of detecting the onset of metabolic acidosis. Wasserman et al. (73) demonstrated that perhaps the impact of a variety of test protocols may have been minimal. They used two test protocols, in both, the initial work rate consisted of pedalling on a bicycle ergometer at zero watts for four minutes followed by increments of 25 watts (150 KPM/min) at regular intervals. In one case, the increments were made every minute while in the other they were made every four minutes. Although their results indicated that the magnitudes of the lactate increase and the bicarbonate decrease were less for the one minute increment test, the point at which the onset of metabolic acidosis was detected was the same for both tests. The role of muscle fibre types and the activities of various enzymes association with aerobic or anaerobic metabolism in the onset of metabolic acidosis was as yet unclear (37,60).

The minimum thresholds found for the onset of metabolic acidosis have appeared to correspond to the oxygen consumption necessary to walk at a comfortable pace (22,73). The most comfortable walking pace has been shown to be at or near the optimal speed based upon minimum energy expenditure (5).

The exercise intensity necessary for an onset of metabolic acidosis appeared to be to some degree related to the individual's degree of training. The most highly fit, cardiorespiratory maximal oxygen uptake in excess of 70 ml/kg/min, seemed to delay the onset of metabolic acidosis to high levels of exercise intensity (16,32). The most comfortable speeds of running found in the literature, appeared to correspond, to some extent, with the speeds found for the onset of metabolic acidosis of subjects of varying degrees of training. It also appeared that long distance athletes tended to perform at a race pace which closely approximated the running velocity at which lactate would have began to accumulate in their blood plasma (16,32,60). Should a dependable relationship exist between the onset of metabolic acidosis and the most comfortable speed of locomotion, either walking or running, then the most comfortable speed could be used in the prescription of exercise intensity for weight reduction or athletic training.

CHAPTER 3

METHODS AND PROCEDURES

Sample Selection

A total of 40 subjects, 20 males and 20 females volunteered to take part in this study. All subjects were University of Alberta students from a variety of faculties. The sample population was subsequently divided into four groups of ten, based on fitness level.

The Beckman Metabolic Measurement Cart

This system has been designed to facilitate rapid assessment of respiratory and metabolic parameters both at rest and during exercise. Briefly, the use of the Beckman Cart in this study was as follows:

Each subject was connected to the Cart with a three way high-velocity Hans-Rudolph non-rebreathing valve and mouthpiece which permitted, through open circuit spirometry, the inhalation of atmospheric air and exhalation through low resistance tubing into the analyzing assembly of the Beckman Metabolic Measurement Cart (81). A low resistance high-velocity, volume transducer provided an accumulation measure of expired air volume over 30 second intervals. Aliquot samples of the expired air was analyzed for percent carbon dioxide and oxygen, using a Beckman LB-2 CO_2 analyzer and Beckman OM-11 O_2 analyzer respectively. The associated programmable calculator overseeing the operation of the measurement cycles, performed all required calculations and printed the following data: $\dot{V}_E$, ml/min BTPS; $\dot{V}O_2$, ml/min and ml/kg/min STPD; CO_2, ml/min STPD; and respiratory exchange ratio, as well as input data every 30 seconds.

Further details regarding this system and its available programs are available in the article by Wilmore et al (81).

Calibration of the Beckman Metabolic Measurement Cart

At the beginning of each testing session that this system was to be used, it was calibrated for volume, partial pressures of oxygen and carbon dioxide, barometric pressure and temperature according to standards recommended in the manual supplied with the instrument, so as to ensure accurate measurements.

Prior to each measurement on a subject, the system was calibrated using a mixture of 17.55% oxygen and 2.99% carbon dioxide calibration gas. Following each measurement on a subject, the system was recalibrated to check for the reliability of the measurements.

Testing Procedures

Testing was carried out over a period of 8 weeks during which time each subject attended three testing sessions. Sessions were scheduled at the same time of day and as close together as possible (mean = 5.8 days). Each subject was instructed to avoid vigorous physical activity and ingesting any foods or nutrients for at least two hours prior to each testing session. The complete instructions to the subjects are available in Appendix B.

Session 1

Treadmill Familiarity

This first visit to the laboratory served as a familiarity session for each subject. Since many subjects had not walked or run on a motor driven treadmill before, this experience was provided, prior to the actual testing proper. Each subject walked and ran on the treadmill at several speeds which served to reduce anxiety associated with the treadmill.

Session 2:

Determination of the Optimal Speeds of Walking and Running

The purpose of this session was threefold: (a) to determine the optimal speed of walking; (b) the optimal speed of running, as well as, c) the steady state oxygen consumption at these speeds.

(a) Optimal Speed of Walking

As a precautionary measure, the subject was connected with with a set of electrodes and cardiotachometer (Cardionics AB, Stockholm) so that heart rate could be monitored throughout the testing session. The motor driven treadmill was started at its slowest speed with the grade held constant at zero degrees. The subject stepped on to the treadmill and at their direction, the speed was gradually increased until the comfortable pace was obtained. The treadmill speed was then increased and decreased several times above and below this speed to ensure that the speed selected was in fact the most comfortable speed.

In cases where the subject was uncertain, then the lower speed was chosen as the most comfortable speed in an attempt to standardize any error.

Following 5 minutes of rest, the subject returned to the treadmill and performed 6 minutes of walking at the most comfortable speed previously chosen. Six minutes of walking at a submaximal intensity allowed the subject to develop a steady state of oxygen consumption (2, p. 296, 48, p. 24).

Any minor change in treadmill speed to better suit the subject was done during the six minute walk protocol on the command of the subject. Any minor alterations that were necessary helped to ensure that the speed chosen was subjectively most comfortable.

(b) Optimal Speed of Running

Following 15 minutes of rest, the subject continued on to the second part of session two, the determination of his or her most comfortable speed of running. The basic procedure for the determination of the optimal speed of walking was repeated for running. The initial treadmill speed for each subject was his or her optimal speed of walking and was increased on the command of the subject. Following 10 minutes of rest, the subject performed 6 minutes of running at his or her optimal speed, to determine the steady state oxygen consumption associated.

(c) Estimation of Percent Body Fat

The final phase of the second session was the estimation of percent body fat. The subjects' body weight was first determined in air on a balance scale. The subjects, who wore light weight swimsuits, then entered the densitometry tank and were seated on a metal chair suspended from the ceiling by a load cell which was connected to a Sargeant recorder, model SR. Each subject was secured to the chair with a diver's belt to ensure that they did not float up during submersion. While seated in the chair the subjects' vital capacity was determined with the aid of a vitalometer from which the lungs residual volume was estimated. The residual volume was based upon the estimate of 30 percent of the vital capacity for men and 25 percent of the vital capacity for women (18,80). A minimum of three trials were performed with the largest vital capacity attaining being recorded.

Each subject was requested to take a maximal inspiration and slowly submerge themselves underwater. The subject was required to hold the volume of air inspired until the underwater weight measurement was recorded. The procedure for underwater weighing was repeated a minimum of three trials. The average of the last two trials was recorded. The body density of each subject was estimated based upon the body density formula derived by Brozek et, al. (12).

Session 3

The Determination of Maximal Oxygen Consumption and Estimation of the Onset of Metabolic Acidosis

The third testing session for each subject was the evaluation of the onset of metabolic acidosis and maximal oxygen consumption. Since no standardized protocol existed for the detection of the onset of metabolic acidosis on the motor driven treadmill (40,66), the protocol followed was based upon guidelines suggested by Wasserman et al. (73). The test protocol for the detection of the onset of metabolic acidosis via gas exchange parameters to yield valid and accurate results must exhibit the following: (a) The test should be initiated at very low work intensities. If the test is started at even low to moderate work intensities the onset of metabolic acidosis may have already been surpassed for some individuals. (b) The work intensity should be increased gradually at regular intervals. (c) The duration of work at each intensity should not be too short or too long. Too short a duration (less than 30 seconds) tends to result in threshold values which are misleadingly high. Too long a duration (more than 3 minutes) at each work intensity may allow the subject to reach a steady state of oxygen consumption which makes the point of gas exchange criteria difficult to determine, and therefore, may result in an inaccurate value. As well, undue stress may be placed on the subject by intervals of long duration, especially at high work intensities. (d) The initial workload intensities serve quite adequately as a warm up.

Each subject's initial workload was 4% of the treadmill's maximal speed (or approximately 15 m/min) below the chosen optimal speed of walking. This workload was maintained for one minute at zero percent grade. Each subsequent workload was increased by 4% of the treadmill's maximum speed each minute. Each subject was connected to the Beckman Metabolic Measurement Cart, in the same manner as with the steady state walking and running at optimal speeds, the previously outlined data being calculated every 30 seconds. Three workloads past the previously determined optimal speed of running (approximately 45 metres per minute) the speed was no longer increased but rather the treadmill grade of inclination was increased 3.0 degrees per minute until maximal oxygen was reached, or the subject no longer felt that he or she could continue. Criteria for the assessment of maximal oxygen consumption was an increase of less than 150 millilitres of oxygen between subsequent work intervals (67) or volitional exhaustion.

The criteria for the onset of metabolic acidosis was that described by Reinhard et al. (59). The systematic increase in the ventilatory equivalent for oxygen (VE/VO_2/min) from its minimum without an increase in the ventilatory equivalent for carbon dioxide (VE/VCO_2/ min). An increase of the ventilatory equivalent for oxygen from its minimum was always the result of a hyperventilation with respect to oxygen consumption (47,59). The validity of this criteria has been reported as a correlation coefficient of r = 0.94 with blood gas analysis sampled at one minute intervals during an incremental test (59). Davis et al. (23) has reported a reliability coefficient of r = 0.91 for the use of the ventilatory equivalent for oxygen in detecting the onset of metabolic acidosis both prior to and following nine weeks of training. The analysis of the ventilatory equivalent was both a valid and reliable method for ergospirometrical measurement of the onset of metabolic acidosis that has been used successfully by several researchers (21,22, 34,55,70).

Following the maximal oxygen uptake tests on all subjects, both males and females were ranked based upon the percentage of maximal oxygen consumption at the onset of metabolic acidosis. This created four new groups of ten subjects, 10 high fit males, 10 high fit females, 10 low fit males and 10 low fit females.

Statistical Treatment

The statistical treatment of the data generated was analyzed by one and two-way analysis of variance. These methods are described by Winer (83). Post hoc procedures, where appropriate, were performed using a Scheffe test for determining significant mean differences. Significant differences were accepted at the alpha level $P < .05$ where was the probability that no difference exists between means. The statistic packages, ANOV 16 and ANOV 25 of the Division of Educational Research Services were used for the statistical analyses. An Amdahl 470 V/6 computer was used to process the data.

CHAPTER 4

RESULTS AND DISCUSSION

Analysis of Results

The following anthropometrical data, the means and standard deviations of which are given in Table 1, were collected from each subject: age in years, height in centimetres, and mass in kilograms. These measurements were taken with the subject wearing shorts, T shirt, and no shoes. Also given in Table 1 is the mean percent body fat estimated by densitometry and lean body weight in kilograms (12). The data presented in Table 1 was partitioned into the four groups based upon fitness rankings. The individual values for all the above measurements are in Tables 29, 30, 31, and 32, Appendix E.

Table 2 contains a summary of the variables that were analyzed in the present study. The mean values along with standard deviations have been included for the four groups of subjects; high fit males, low fit males, high fit females, low fit females, based on, the percentage of maximal oxygen consumption at the onset of metabolic acidosis.

The data of Figure 1 is an example of the ventilatory equivalent for oxygen results that were obtained for two subjects (subjects number 17 and 23). The graphs of the data of these two individuals were selected as representative of the high and low fitness groups. The individuals of the high fit groups, both male and female tended to

Table 1 - Characteristics of High and Low Fitness Male and Female Subjects

CHARACTERISTICS	HIGH FIT MALES	LOW FIT MALES	HIGH FIT FEMALES	LOW FIT FEMALES
Age (years)	22.3 ± 2.4	23.1 ± 4.8	21.9 ± 2.3	20.4 ± 1.9
Height (centimetres)	181.6 ± 5.5	178.9 ± 8.8	167.4 ± 5.4	166.9 ± 5.5
Mass (kilograms)	76.0 ± 7.3	79.7 ± 13.4	62.0 ± 6.4	59.1 ± 7.2
Percent Body Fat	9.0 ± 3.9	15.0 ± 4.5	20.3 ± 6.6	21.6 ± 3.3
Lean Body Weight (kilograms)	68.9 ± 6.5	66.7 ± 10.2	48.3 ± 5.1	46.3 ± 5.1

Table 2 - Summary of the Pertinent Variables Analyzed for the Four Groups Under Study, Means and Standard Deviations Shown

OUTPUT VARIABLES	HIGH FITNESS MALES	LOW FITNESS MALES	HIGH FITNESS FEMALES	LOW FITNESS FEMALES
Walking Speed m/min	90.0 ± 11.1	87.5 ± 10.1	82.3 ± 8.9	79.2 ± 8.70
Walking Oxygen Consumption ml/kg/min	14.5 ± 1.85	14.3 ± 4.13	13.0 ± 2.82	13.2 ± 1.38
Steady State Walking Heart Rate	99 ± 10.8	107 ± 11.4	101 ± 10.1	104 ± 12.4
Running Speed m/min	174.6 ± 15.1	160.9 ± 16.2	152.5 ± 15.1	145.6 ± 16.4
Running Oxygen Consumption ml/kg/min	33.4 ± 3.69	30.6 ± 4.19	29.7 ± 2.72	27.7 ± 3.03
Steady State Running Heart Rate	152 ± 12.0	149 ± 8.1	152 ± 10.3	154 ± 14.2
Onset of Metabolic Acidosis Speed m/min	164.6 ± 12.7	124.1 ± 17.9	143.7 ± 14.1	117.0 ± 21.3
Onset of Metabolic Acidosis ml/kg/min	30.4 ± 3.35	19.5 ± 3.20	27.2 ± 2.81	20.1 ± 3.86
Onset of Metabolic Acidosis Heart Rate	146 ± 10.2	122 ± 11.2	144 ± 8.5	129 ± 8.6

Table 2 - Continued

OUTPUT VARIABLES	HIGH FITNESS MALES	LOW FITNESS MALES	HIGH FITNESS FEMALES	LOW FITNESS FEMALES
Max VO_2 Speed m/min	247.8 ± 21.07	231.9 ± 20.59	221.2 ± 18.98	211.6 ± 26.26
Max VO_2 Treadmill Grade - degrees	5.11 ± 0.92	4.77 ± 0.47	3.98 ± 0.50	4.61 ± 0.98
Max VO_2 ml/kg/min	48.4 ± 4.97	43.8 ± 4.78	39.9 ± 6.42	34.8 ± 11.31
Heart Rate at Max VO_2	192 ± 7.33	186 ± 11.79	189 ± 5.8	191 ± 9.1
Power Output at Max VO_2 kg/metres/min	950.14 ± 155.62	851.25 ± 186.15	547.11 ± 136.28	560.32 ± 168.14
% of Max VO_2 at Onset of Metabolic Acidosis	63.0 ± 4.96	44.7 ± 6.13	66.46 ± 6.25	52.2 ± 6.04
% of Onset of Metabolic Acidosis Speed at Running Speed	108.4 ± 11.06	131.2 ± 17.58	106.52 ± 9.85	127.36 ± 22.65

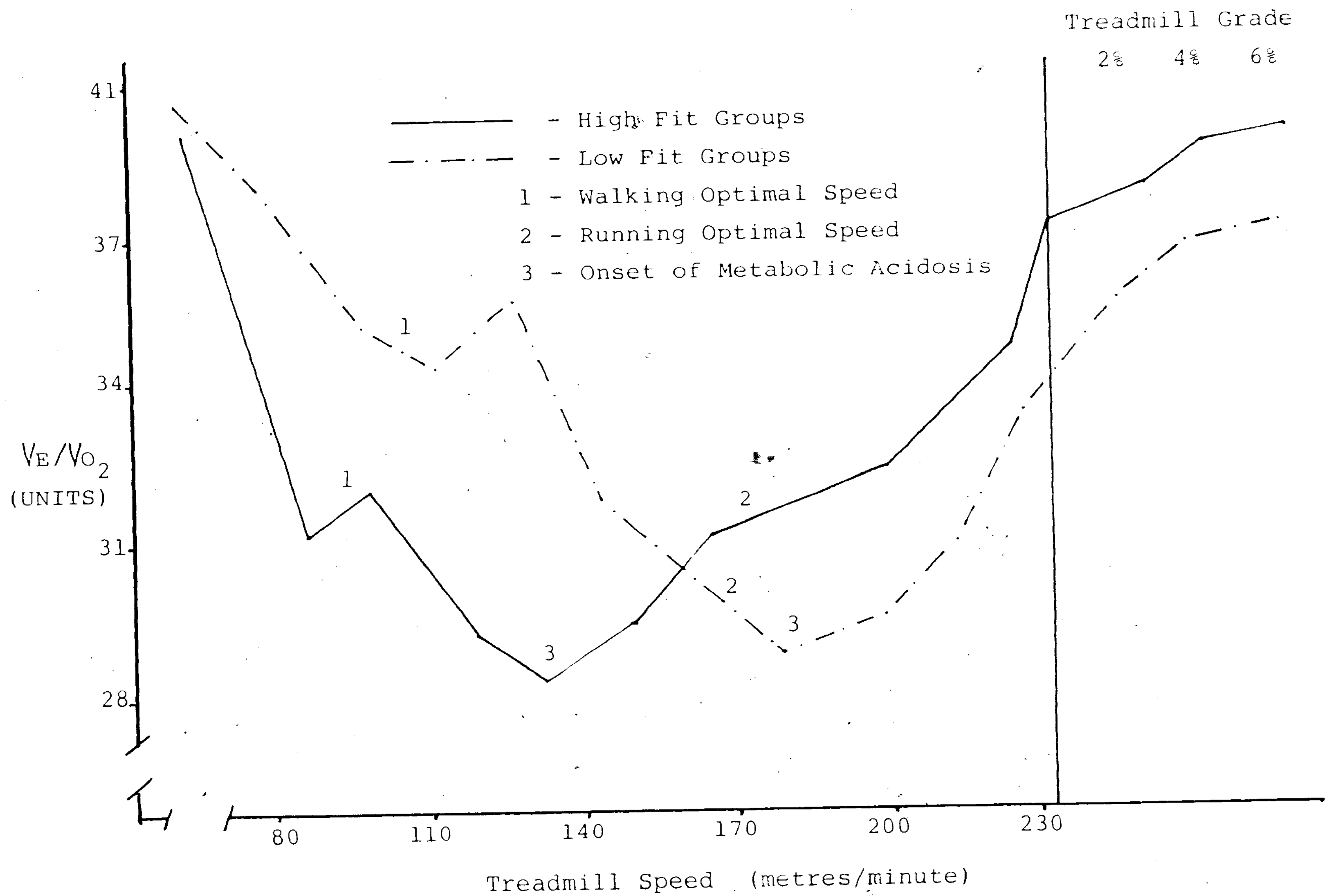

Figure 1 The Ventilatory Equivalent During Progressive Intensity Treadmill Running for Subjects Representative of High and Low Fitness Groups

depict an onset of metabolic acidosis in close proximity to their chosen optimal speed of running. On the other hand, the subjects of the low fitness groups tended to show that their selection of an optimal speed of running was well in excess of their onset of metabolic acidosis.

The Treadmill Speeds at the Optimal Speed of Walking and the Onset of Metabolic Acidosis

Figure 2 contains the mean data of treadmill speeds at optimal speed walking and at the onset of metabolic acidosis for the four groups: high fit males, low fit males, high fit females, and low fit females.

The one-way analysis of variance of the optimal speed of walking rev[illegible] that there were no significant differences between the four gro[illegible] (P >.05). This analysis is found in Appendix E, Table 5.

The one-way analysis of variance and subsequent Scheffe Test for the treadmill speed at the onset of metabolic acidosis showed a significant ($P < .05$) fitness difference (Tables 8 and 9) Appendix E. High fit males had their onset of metabolic acidosis at significantly different treadmill speeds than did the low fit males or low fit females. There was also a significant difference between the high fit females and low fit females.

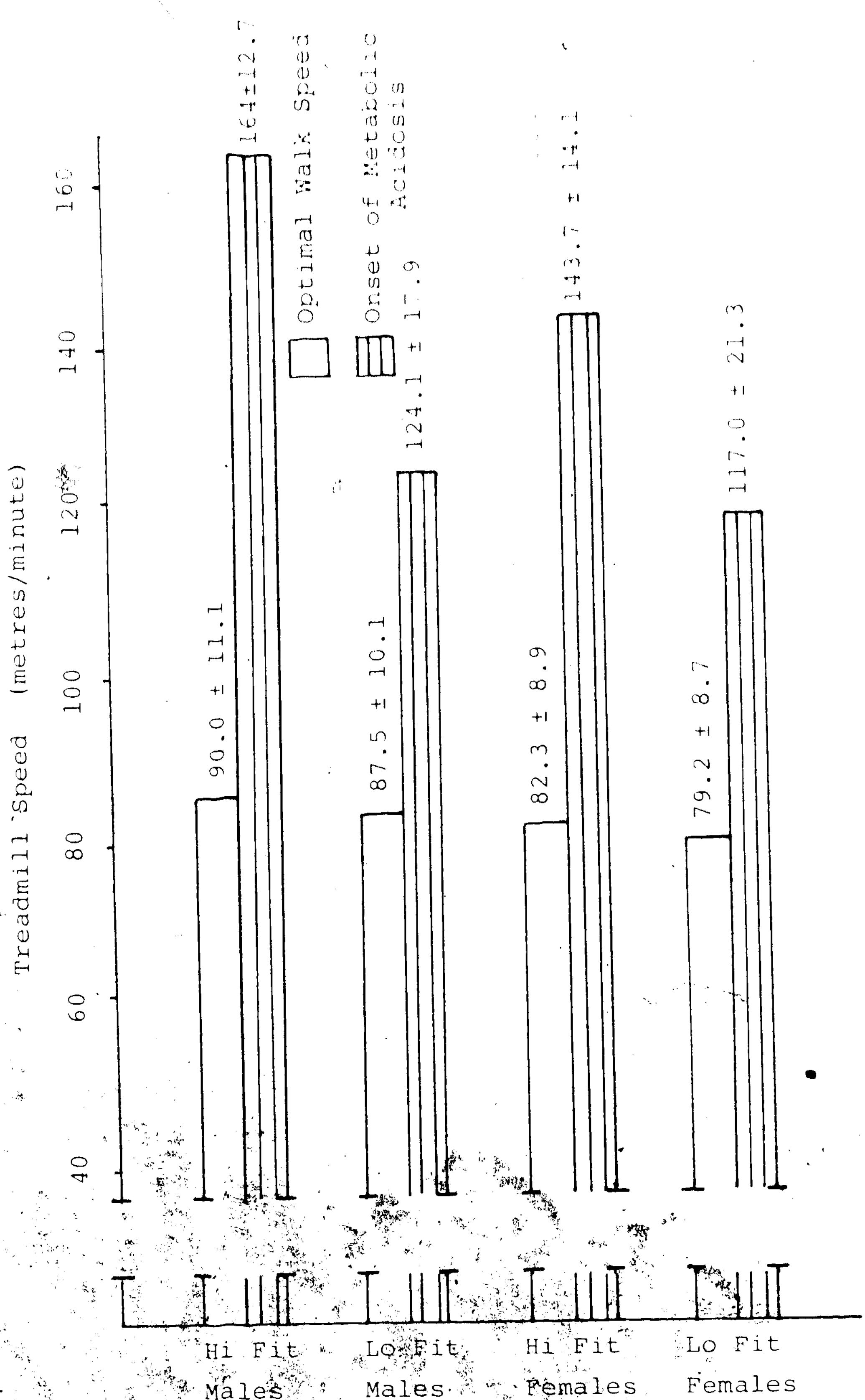

Figure 2 Treadmill Speeds at the Optimal Speed of Walking and the Onset of Metabolic Acidosis

A Scheffe Test was performed on the mean data of optimal speed walking and the treadmill speed at the onset of metabolic acidosis, to determine significant differences in these two measures, within each of the four groups. There was a significant difference ($P < .05$) between the optimal speed of walking and the onset of metabolic acidosis within each of the four groups (Table 10).

In the statistical two-way analysis of variance for the hypothesis that there would be no significant difference between the speeds at optimal walking and at the onset of metabolic acidosis in the four groups, the terms speed and groups refer to the following:

(1) Speed - the treadmill speed selected for optimal walking and the treadmill speed at the onset of metabolic acidosis.

(2) Groups - refers to the four groups of subjects: high fit males, low fit males, high fit females, and low fit females.

Treadmill speed showed a significant "A" main effect ($P < .05$) and the four groups showed a significant "B" main effect ($P < .05$). Significant interaction occurred between the treadmill speeds and the four groups (Table 19) Appendix E.

A Scheffe Test performed on the four groups showed a significant differenct ($P < .05$) in the selection of an optimal speed of walking and the speed at the onset of metabolic acidosis for high and low fitness groups of the same sex (Table 20) Appendix E. There was a significant difference between the high fit males and high fit females but not between low fit males and low fit females ($P < .05$). There was no significant difference between the low fit males and high fit females.

The Treadmill Speeds at the Optimal Speed of Running and the Onset of Metabolic Acidosis

Figure 3 contains the mean data of treadmill speeds at the optimal speed of running and at the onset of metabolic acidosis for the four groups.

The one-way analysis of variance of the optimal speed of running revealed a significant difference between the four groups (Table 6) Appendix E. A Scheffe Test showed that there was a significant difference between the high fit males and the low fit females ($P < .05$) (Table 7) Appendix E.

As was noted in the previous section, there was a significant difference between fitness groups in the treadmill speed at the onset of metabolic acidosis (Tables 8 and 9) Appendix E. High fit males had their onset of metabolic acidosis at significantly ($P < .05$) different treadmill speeds than the low fit males or low fit females. There was also a significant difference between the high fit females and low fit females.

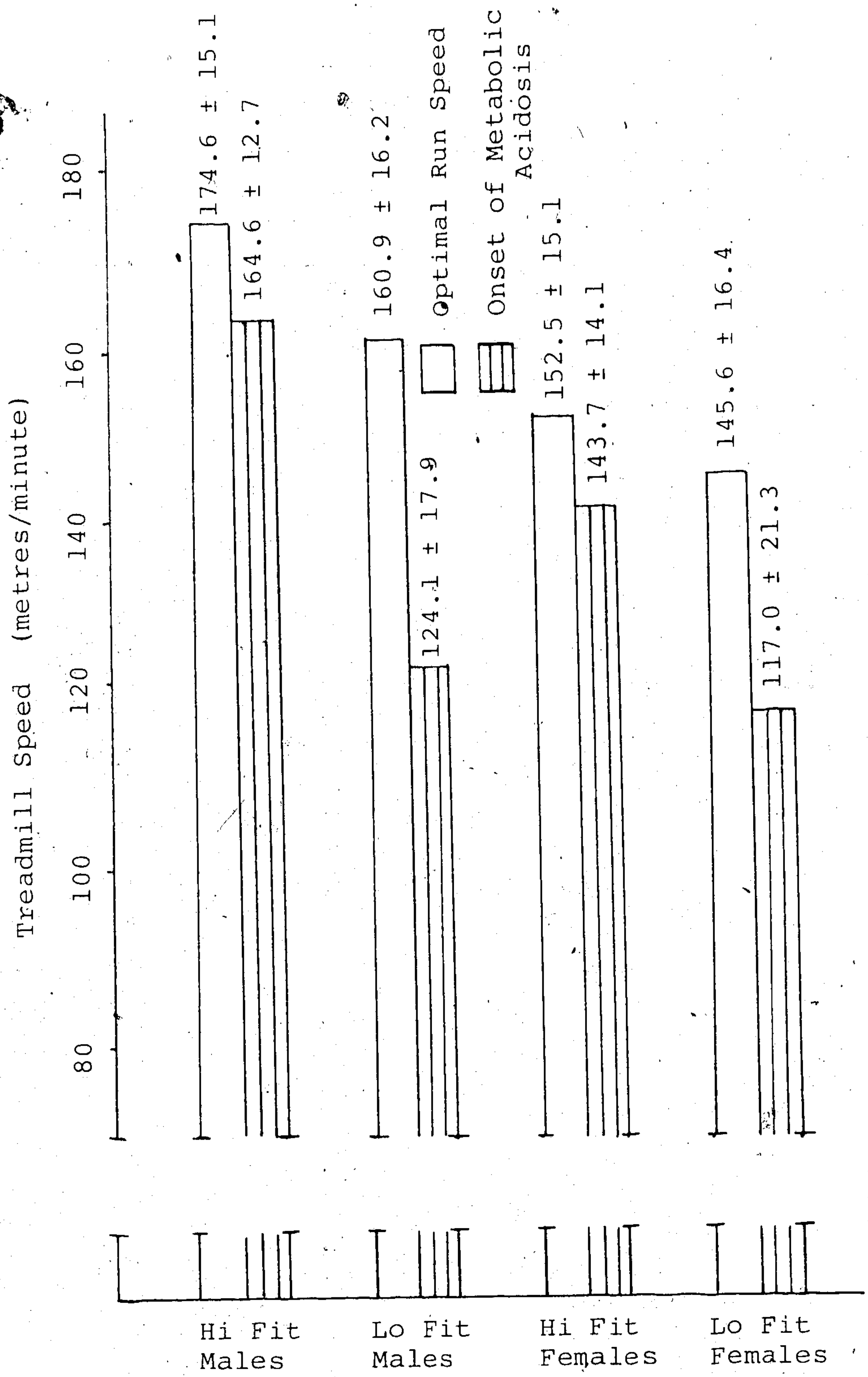

Figure 3 Treadmill Speeds at the Optimal Speeds of Running and the Onset of Metabolic Acidosis

A Scheffe Test was performed on the mean data of optimal speed running and the treadmill speed at the onset of metabolic acidosis to determine significant differences in these two measures within each of the four groups. There was no significant difference ($P > .05$) between the treadmill speed of optimal running and the onset of metabolic acidosis for the high fit male group (Table 11) Appendix E. There was also no significant difference between these variables for both the high and low fit female groups. There was a significant difference between the treadmill speed of optimal running and the onset of metabolic acidosis for the low fit male group.

In the statistical two-way analysis of variance for the hypothesis that there would be no significant difference between the speeds at optimal running and at the onset of metabolic acidosis speed in the four groups, the terms speed and groups refer to the following:

(1) Speed - the treadmill speed selected for optimal running and the treadmill speed at the onset of metabolic acidosis.

(2) Groups - refers to the four groups of subjects: high fit males, low fit males, high fit females, and low fit females.

Treadmill speed showed a significant "A" main effect ($P < .05$) and the four groups showed a significant "B" main effect ($P < .05$). Significant interaction occurred between the treadmill speeds and the four groups (Table 21) Appendix E.

A Scheffe Test performed on the four groups showed a significant difference ($P < .05$) for high and low fitness groups of the same sex (Table 22) Appendix E. There was a significant difference between the high fit males and high fit females but not between low fit males and females ($P > .05$). There was no significant difference between the low fit males and high fit females.

<u>The Steady State Relative Oxygen Consumption During Walking at Optimal Speed and the Relative Oxygen Consumption at the Onset of Metabolic Acidosis</u>

Figure 4 contains the mean data of relative oxygen consumption at the optimal speed of walking and at the onset of metabolic acidosis for the four groups.

The one-way analysis of variance of the relative oxygen consumption at steady state optimal speed walking revealed that there were no significant ($P > .05$) differences between the four groups (Table 12) Appendix E.

The one-way analysis of variance for the relative oxygen consumption at the onset of metabolic acidosis showed a significant ($P < .05$) difference between the four groups (Table 15) Appendix E. A Scheffe Test showed that there were significant differences between high and low fitness groups ($P < .05$) (Table 16) Appendix E. High fit males showed a significant difference between the low fit males and

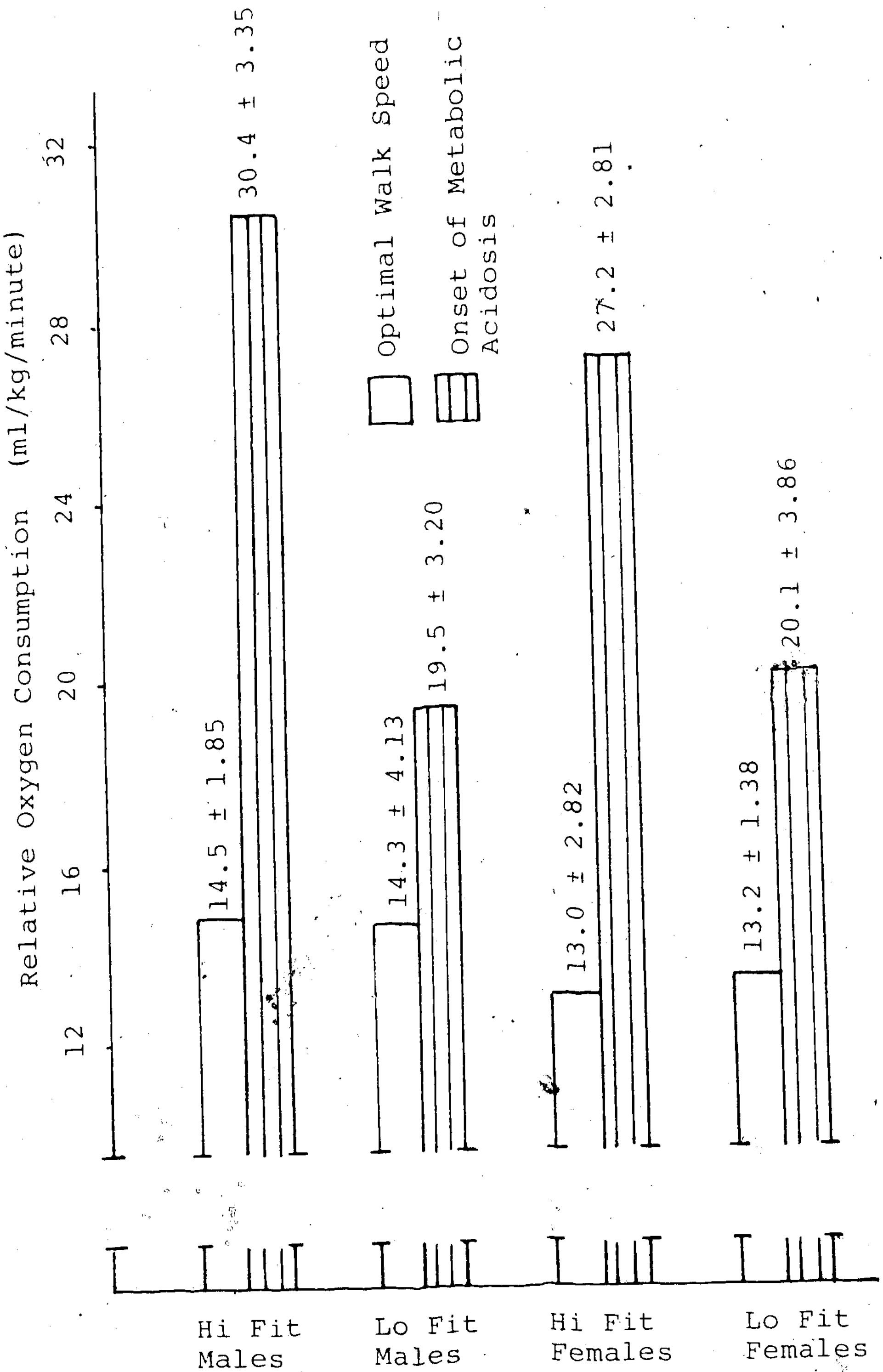

Figure 4 Relative Oxygen Consumption at the Optimal Speed of Walking and the Onset of Metabolic Acidosis

between the low fit females. The high fit females differed significantly, at the onset of metabolic acidosis, from the low fit males and low fit females also. There was no significant difference between high fit males and high fit females or low fit males and low fit females.

A Scheffe Test was performed on the mean data of the relative oxygen consumption at the optimal speed of walking and at the onset of metabolic acidosis to determine significant differences in these measures within each of the four groups (Table 17) Appendix E. There were significant ($P < .05$) differences in the relative oxygen consumption at optimal speed walking and at the onset of metabolic acidosis within three groups; high fit males, high fit females and low fit females. There was no significant difference in the low fit male group ($P > .05$).

In the statistical two-way analysis of variance for the hypothesis that there would be no significant difference between the relative oxygen consumption at steady state optimal speed walking and the relative oxygen consumption at the onset of metabolic acidosis in the four groups, the terms relative oxygen consumption and groups refer to the following:

(1) Relative Oxygen Consumption - the oxygen consumption during steady state optimal speed walking and the oxygen consumption at the onset of metabolic acidosis.

(2) Groups refers to the four groups of subjects: high fit males, low fit males, high fit females, and low fit females.

Relative oxygen consumption showed a significant "A" main effect ($P < .05$) and the four groups showed a significant "B" main effect ($P < .05$). Significant interaction occurred between the oxygen consumption and the four groups (Table 23) Appendix E.

A Scheffe Test performed on the four groups showed a significant difference ($P < .05$) in the relative oxygen consumption at the optimal speed of walking and the onset of metabolic acidosis for high and low fitness groups of the same sex (Table 24) Appendix E. There was no significant difference between the groups of similar fitness level and opposite sex ($P > 05$). There was no significant difference between low fit males and high fit females.

The Steady State Relative Oxygen Consumption During Running at Optimal Speed and the Relative Oxygen Consumption at the Onset of Metabolic Acidosis

Figure 5 contains the mean data of relative oxygen consumption at the optimal speed of running and at the onset of metabolic acidosis for the four groups.

The one-way analysis of variance of the relative oxygen consumption at steady state optimal speed running revealed that there was a significant difference between the four groups (Table 13) Appendix E. A Scheffe Test showed that the difference occurred between the high fit males and the low fit females ($P < .05$) (Table 14) Appendix E.

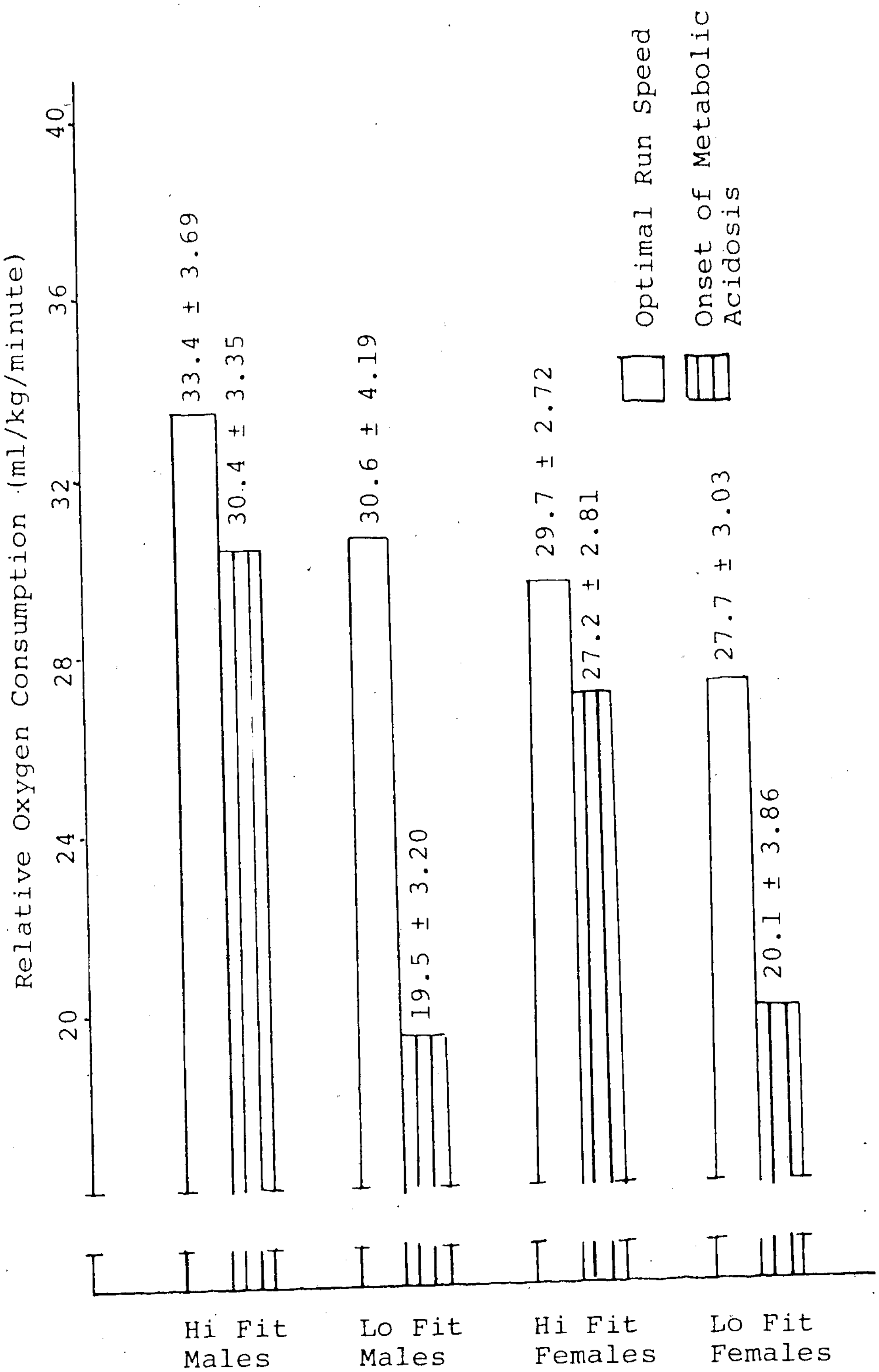

Figure 5 Relative Oxygen Consumption at the Optimal Speed of Running and the Onset of Metabolic Acidosis

The one-way analysis of variance and subsequent Scheffe Test for the relative oxygen consumption at the onset of metabolic acidosis showed a significant difference between high and low fitness groups as outlined in the previous section (Table 15 and 16) Appendix E. High fit males showed a significant difference between the low fit females (P <.05). The high fit females differed significantly, at the onset of metabolic acidosis, from the low fit males and low fit females also. There was no significant difference between high fit males and high fit females or low fit males and low fit females.

A Scheffe Test was performed on the mean data of relative oxygen consumption at the optimal speed of running and at the onset of metabolic acidosis to determine significant differences in these measures within each of the four groups (Table 18) Appendix E.

There was no significant difference (P > .05) between the relative oxygen consumption at the optimal speed of running and the onset of metabolic acidosis in both the high fit male and high fit female groups. Both low fitness groups showed significant differences in the relative oxygen consumption at these two measures (P <.05).

In the statistical two-way analysis of variance for the hypothesis that; there would be no significant difference between the relative oxygen consumption at steady state optimal speed running and the relative oxygen consumption at the onset of metabolic acidosis in the four groups, the terms relative oxygen consumption and groups refer to the following:

(1) Relative Oxygen Consumption - the oxygen consumption during steady state optimal speed running and the oxygen consumption at the onset of metabolic acidosis.

(2) Groups - refers to the four groups of subjects; high fit males, low fit males, high fit females, and low fit females.

Relative oxygen consumption showed a significant "A" main effect ($P < .05$) and the four groups showed a significant "B" main effect ($P < .05$). Significant interaction occurred between the oxygen consumption and the four groups (Table 25) Appendix E.

A Scheffe Test performed on the four groups showed a significant difference ($P < .05$) in the relative oxygen consumption at the optimal speed of running and the onset of metabolic acidosis for high and low fitness groups of the same sex (Table 26) Appendix E. There was a significant difference between high fit males and high fit females but not between low fit males and low fit females ($P < .05$).

The Selection of an Optimal Speed of Running in Relation to the Treadmill Speed that Exhibited the Onset of Metabolic Acidosis

Table 3 shows the distribution of individuals in each of the four groups, in terms of the selection of an optimal speed of running as a percentage of the speed at the onset of metabolic acidosis.

Table 3 - Summary of the Selection of an Optimal Speed of Running in Relation to the Treadmill Speed at the Onset of Metabolic Acidosis in Males and Females of High and Low Fitness

GROUPS	OPTIMAL SPEED OF RUNNING AS A PERCENTAGE OF ONSET OF METABOLIC ACIDOSIS								
	90-94	95-99	100-104	105-109	110-114	115-120	120	MEAN	S.D.
High Fitness Males	1	1	2	1	1	3	1	108.4%	11.06
Low Fitness Males			2			1	7	131.2%	17.58
High Fitness Females	1	1	2	3	1		2	106.5%	9.85
Low Fitness Females		1	1		1	2	5	127.4%	22.70

(a) High Fitness Males

Fifty percent of these subjects selected an optimal speed of running which was ± 10% of the speed at the onset of metabolic acidosis. The mean speed was 108.40% of the speed at the onset of metabolic acidosis with a standard deviation of 11.06%.

(b) Low Fitness Males

Seventy percent of these subjects selected an optimal speed of running which was greater than 120% of the speed at the onset of metabolic acidosis, the mean speed was 131.20% ± 17.58%.

(c) High Fitness Females

Seventy percent of the high fit females chose an optimal speed of running which was ± 10% of the speed at the onset of metabolic acidosis. The average speed for this group was 106.50% with a standard deviation of ± 9.85%.

(d) Low Fitness Females

Seventy percent of the females chose an optimal speed of running which was in excess of 115% of the speed at the onset of metabolic acidosis. The mean speed was 127.40% ± 22.70%.

Figure 6 contains the mean data of the optimal speed of running as a percentage of the speed at the onset of metabolic acidosis for the four groups. The optimal speed of running chosen as a percentage of

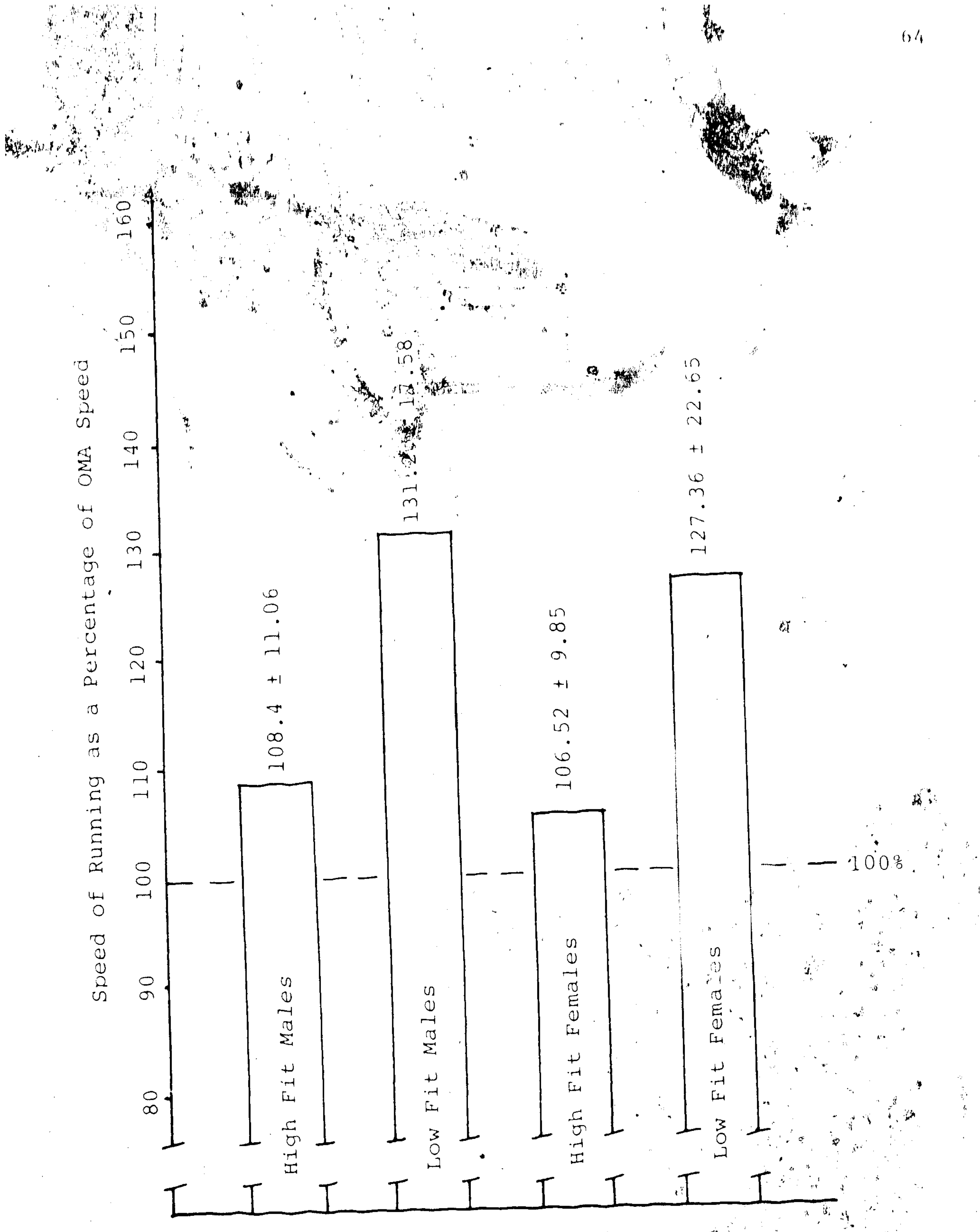

Figure 6 The Selection of an Optimal Speed of Running in Relation to the Speed at the Onset of Metabolic Acidosis

the speed at the onset of metabolic acidosis was analyzed by using a two-way analysis of variance. The factors were sex, male or female; and fitness, high or low. Male or female showed no significant "A" main effect (P > .05) while high and low fitness groups showed a significant "B" main effect (P < .05). There was no significant interaction between sex and fitness groups (Table 27) Appendix E.

There was no significant difference (P > .05) between the males and females in the selection of an optimal speed of running as a percentage of the treadmill speed at the onset of metabolic acidosis. There was a statistically significant difference (P < .05) between high and low fitness groups in the selection of an optimal speed of running as a percentage of the treadmill speed at the onset of metabolic acidosis. The high fitness groups selected optimal speeds of running that were closer to those treadmill speeds that were associated with their onset of metabolic acidosis than did the low fitness groups

The Power Output at Maximal Oxygen Consumption with Fitness Ranking and Sex as Determining Factors

Figure 7 contains the mean power output of maximal oxygen consumption for the four groups. The power output generated during a one minute time frame while at maximal oxygen consumption was analyzed by using a two-way analysis of variance. The factors were sex, male or

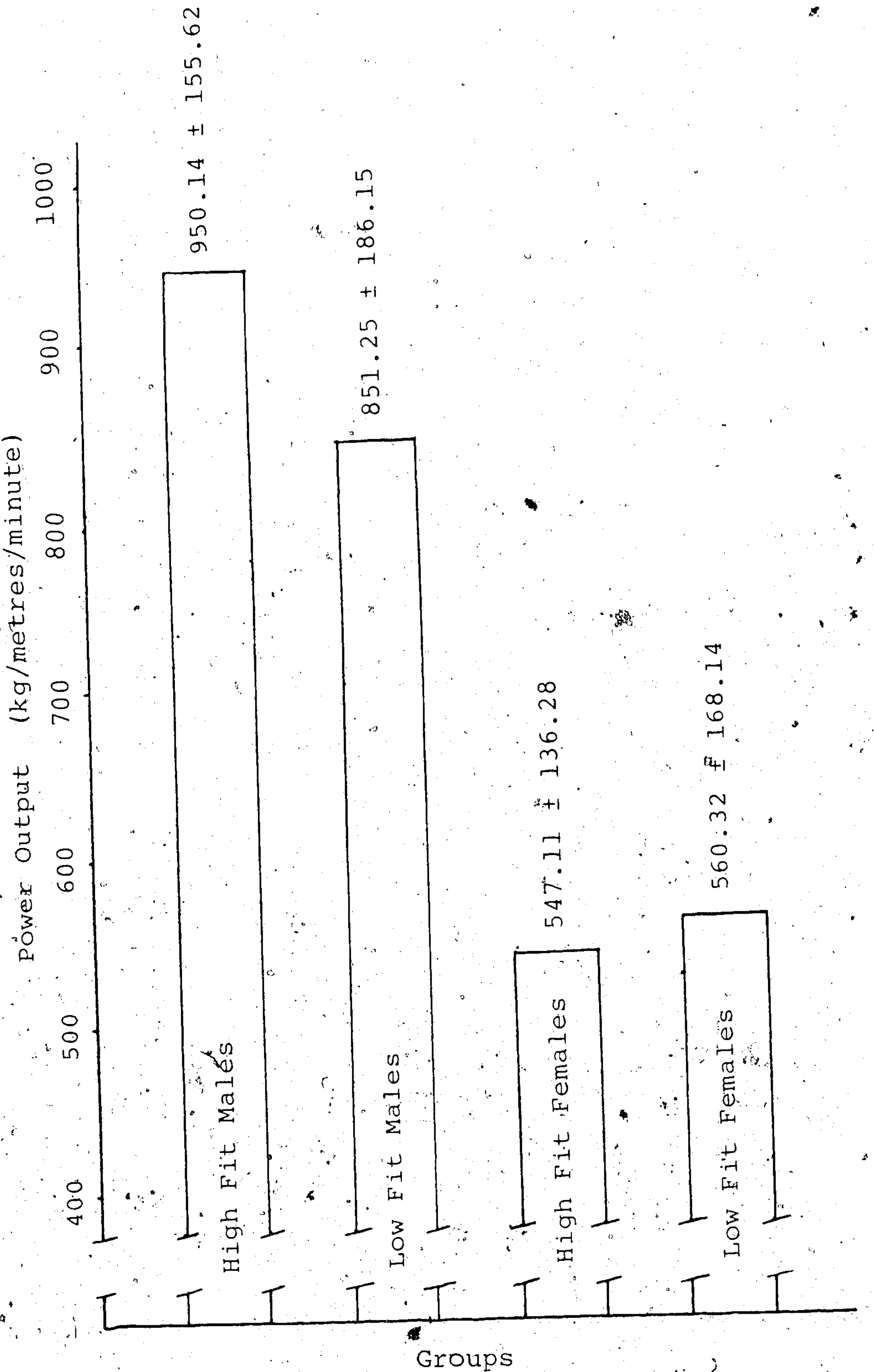

Figure 7. The Power Output at Maximal Oxygen Consumption for the Four Groups

female; and fitness, high or low. Male or female showed a significant "A" main effect ($P < .05$) while high and low fitness groups showed no significant "B" main effect ($P > .05$). There was no significant interaction between sex and fitness groups, therefore the least squared solution was employed (33,84) (Table 28) Appendix E.

There was a statistically significant difference ($P < .05$) between males and females in power output at maximal oxygen consumption. The males' power output was significantly higher than the females' power output.

DISCUSSION

Optimal Speeds of Walking

Table 2 showed the mean optimal speeds of walking for the four subgroups under study. The individual values are given in Tables 33, 34, 35, and 36, Appendix F.

The one-way analysis of variance of the treadmill speed at the optimal speed of walking showed that there was no statistically significant difference in the treadmill speeds selected by the four groups of subjects. Regardless of sex or fitness it would appear that the selection of an optimal speed of walking was similar in these college age students. The one-way analysis of variance of the relative oxygen consumption at steady state optimal speed walking showed congruent results to treadmill speed. The oxygen consumption at optimal speed walking was not significantly affected by fitness level or sex.

Table 4 contains mean data of Bhambhani (5), Ralston (58), Bobbert (7), Mayhew (48), and the present study, for optimal speeds of walking and running. The females' average selection of an optimal speed of walking was within the range of optimal speeds as summarized by Bhambhani (5). The mean optimal walking speeds of the females was 82.3 metres/minute, high fit and 79.2 metres/minute low fit. These values were higher than the mean value of 74 metres/minute obtained by Ralston (58). The present study's values were similar to the mean value of 80 metres/minute obtained by Zarrugh et. al. (84).

Table 4

Optimal Speeds of Walking and Running Reported in the Literature and Those That Were Found in the Present Study

AUTHOR	OPTIMAL SPEED WALKING		OPTIMAL SPEED RUNNING	
	MALES	FEMALES	MALES	FEMALES
Bhambhani (5)	83.6	79.4	154.9	143.7
Bobbert (7)	84.5			
Mayhew (48)			185.0	
Ralston (54)	74.0	74.0		
Zarrugh (83)	80.0	80.0		
Present Study	88.7	80.7	167.7	149.0

The mean optimal walking speed of the males was slightly beyond the range of optimal speeds as summarized by Bhambhani (5), as a maximum of 85 metres/minute. The mean optimal walking speeds in high fit males, 90 metres/minute and the low fit males, 87.5 metres/minute were both higher than the mean values obtained by Ralston (58), Zarrugh et al. (84), and the mean value of 84.5 metres/minute obtained by Bobbert (7).

One explanation for the rather high mean optimal speeds of walking for the male groups may have been that these subjects were of relatively higher fitness levels in terms of walking than subjects included in the review of literature. A second possible explanation may be that although the subjects were instructed to select a speed which they felt was most comfortable, some male subjects may have selected speeds in excess of comfort because they may have felt a higher speed signified a 'better' performance. Such an overestimation could also have occurred in those studies reported in the literature.

<u>Optimal Speeds of Running</u>

Table 2 showed the mean optimal speeds of running for the four subgroups. The individual values are given in Tables 37, 38, 39 and 40, Appendix F.

The one-way analysis of variance of the treadmill speed at the optimal speed of running showed that there was a significant difference between the four groups. A Scheffe Test to locate the differences revealed that the only significant difference occurred between the two groups of extreme fitness levels, the high fit males and the low fit females. The one-way analysis of variance of the relative oxygen consumption at steady state optimal speed running showed identical results to treadmill speed. The analysis of variance and subsequent Scheffe Test showed that the only significant differences occurred between the two extremities of fitness, the high fit males and the low fit females. This similarity, or rather the lack of dissimilarity in the selection of an optimal speed of running is discussed in more detail under the heading "The Optimal Speed of Running and the Speed at the Onset of Metabolic Acidosis."

The mean optimal running speeds of males and females in this study, 167.7 metres/minute and 149 metres/minute, respectively, was considerably lower than the mean optimal running speed of 185 metres/minute determined by Mayhew (50,51) on his highly trained runners (Table 4). The mean optimal running speeds of the males in this study were, however, somewhat higher than those reported by Bhambhani (5) of 154.9 metres/minute for males, and 143.7 metres/minute for females. Since the high fit males of this study were of similar age and physical activity background these subjects showed a mean optimal speed of running (182.9 metres/minute) which was in agreement with the findings of Mayhew (50). As well, the high fit females, a mean optimal speed of running of 175.6, were also much similar in terms of cardiorespiratory training as the subjects of Mayhew's research, and therefore, were in closer agreement to his reported mean optimal speed of running.

Maximal Oxygen Consumption

Table 2 showed the mean relative maximal oxygen consumption for the four subgroups under study. The individual values are given in Tables 41, 42, 43, and 44, Appendix F.

The VO_2 max values obtained were in agreement with the range of values reported by Mathews and Fox (48) as normal for male and female university students of these ages. Since fitness rankings were based on the percentage of maximal oxygen consumption at the onset of metabolic acidosis rather than the more tradition VO_2 max, the mean values of VO_2 max may be misleadingly low for the 'high fit' groups and misleadingly high for the 'low fit' groups.

A possible source of error in the maximal oxygen consumption data was that it is difficult for individuals of relatively low physical activity to push themselves to VO_2 max, since such levels of stress are uncomfortable and unfamiliar. The maximal heart rate data (Table 2) supports this contention since the low fit individuals had lower maximum heart rate than should be expected (48, p.472). Since VO_2 max data was not of primary importance the impact of this error on the total study was minimal.

The Onset of Metabolic Acidosis

Table 2 showed the mean speeds at the onset of metabolic acidosis, the mean relative oxygen consumptions while at that speed, during the maximal oxygen consumption test, and the mean percentages at maximal oxygen consumption at the onset of metabolic acidosis, for the four groups subsequently assigned. The individual values are given in Tables 45, 46, 47, and 48, Appendix F.

The one-way analysis of variance of the treadmill speed at the onset of metabolic acidosis showed a significant difference in the four groups. A Scheffe Test revealed that there was a significant difference between groups of high and low fitness in the onset of metabolic acidosis regardless of sex. There was no significant difference between the sexes of similar fitness. Once again the one-way analysis of variance of the relative oxygen consumption at the onset of metabolic acidosis was congruent to the results of treadmill speed. A Scheffe Test revealed that there was a significant difference between high and low fitness groups. There was no significant difference between the males and females of similar fitness level. The onset of metabolic acidosis occurred at a significantly higher level in subjects of high fitness than in subjects of low fitness.

Since studies that have examined the onset of metabolic acidosis during locomotion on a treadmill have used only highly trained athletes no data of direct similarity in fitness was available. However some inferential analysis was possible. Volkov et al (69) determined the running speed corresponding to the "threshold of anaerobic metabolism", characterized by an abrupt increase in arterial blood lactate above resting levels, for four highly experienced middle distance runners between 21 and 29 years of age. Subjects that had trained at different intensities and frequencies, similarly, exhibited considerable differences in the speed necessary to initiate lactic acidosis. These critical speeds varied from 156 to 204 metres per minute or 9.4 to 12.3 kilometres per hour. These values may be compared favorably with the high fit male group at the onset of metabolic acidosis which ranged from 152 to 183 metres per minute or 9.1 to 11.0 kilometres per hour. As well, the high fit males under study displayed fairly similar values of maximal oxygen consumption to those reported by Volkov et al. (69). The corresponding speeds at the onset of metabolic acidosis for the low fit group of males and both groups of females were lower than the high fit male group on the average. Of note was the finding that the high fit female group demonstrated a greater delay in the onset of metabolic acidosis in terms of treadmill speed than the low fit male group. This finding appeared to parallel similar findings in terms of maximal oxygen consumption and many performance variables in which highly trained female subjects may exceed untrained males.

The present results for the relationship between the onset of metabolic acidosis and maximal oxygen consumption were in agreement with past literature. Several studies (22,23,40,59,73,76,77) have shown that the onset of metabolic acidosis occurred at approximately 45 - 55 percent of maximal oxygen consumption in the untrained subjects. In the present study the untrained male subjects were, on the average, at the onset of metabolic acidosis at 44% of their maximal oxygen consumption and the female untrained groups were at 52%, both in agreement with previous studies. The high fit group of males were on the average, at the onset of metabolic acidosis at 63% of their maximal oxygen consumption while their female counterparts were on the average, at the onset of metabolic acidosis at 66.5% of their maximal oxygen consumption. These values were in agreement with the works of Green et al. (37) and Nagle et al. (53) who found that the onset of metabolic acidosis occurred at approximately 60 - 75 percent of maximal oxygen consumption in the physically active, non-endurance athlete.

The Optimal Speed of Walking and the Speed at the Onset of Metabolic Acidosis

Figure 2 contained the mean optimal speeds of walking and at the onset of metabolic acidosis for the four groups.

The results of the statistical analysis of the optimal speed of walking showed no statistically significant difference between fitness groups or between males and females in the selection of an optimal speed. Regardless of fitness level males and females tended to select an optimal speed of walking that was similar. In contrast, the statistical analysis of the speed at the onset of metabolic acidosis showed that there was a significant difference between high and low fitness groups. High fit individuals had significantly higher levels of treadmill speed at the onset of metabolic acidosis than did low fit individuals. There was no significant difference between males and females of similar fitness implying that the difference in the onset of metabolic acidosis between high and low fitness groups was unaffected by sex.

There were statistically significant differences between the treadmill speed at the optimal speed of walking and at the onset of metabolic acidosis within all four groups. There was no similarity in these measures within any of the four groups.

The results of the statistical analysis for the difference between the optimal speeds of walking and the treadmill speed at the onset of metabolic acidosis showed that there was a statistically significant difference between the speed at the onset of metabolic acidosis and the chosen optimal speed of walking. The optimal speeds of walking were significantly below those at the onset of metabolic acidosis. Previous research has shown that the lower limit for normal individuals of either sex, and all age groups appears to have been the same (22,73). This lower limit was at an oxygen consumption level equivalent to a consumption for a typical adult to walk at approximately 4 kilometres per hour. It would appear that none of the groups of the present study had their onset of metabolic acidosis at this minimum level.

There was a significant difference between fitness groups in the selection of the optimal speed of walking and the relationship to the onset of metabolic acidosis speed. The low fitness groups had their speeds at the onset of metabolic acidosis nearer their optimal walking speeds, though not statistically significant. There existed a statistically significant difference between the high fit males and high fit females, but not between the low fit males and low fit females, implying that sex differences in the selection of an optimal speed of walking and the speed at the onset of metabolic acidosis occurred at the upper end of the fitness rankings and not the lower end.

The Optimal Speed of Running and the Speed at the Onset of Metabolic Acidosis.

Figure 3 contained the mean optimal speeds of running and at the onset of metabolic acidosis for the four groups. The results of the statistical analysis of the optimal speed of running showed a significant difference between the high fit males and low fit females. There was no statistical difference between any of the other groups. Either the selection of an optimal speed of running was relatively unaffected by fitness level and sex, or, there was inaccuracy in the selection of an optimal speed of running for some individuals. The statistical analysis of the treadmill speed at the onset of metabolic acidosis showed that clearly there was a significant difference between high and low fitness groups. There was no significant difference between males and females of similar fitness levels.

There was a statistically significant difference between the treadmill speed at the optimal speed of running and at the onset of metabolic acidosis within the low fit male group. Both high fitness groups and the low fit female group showed no significant difference in these two measures of treadmill speed. Or conversely, the optimal speed of running and the speed at the onset of metabolic acidosis were essentially the same in these three groups.

The results of the statistical analysis for the difference between the optimal speeds of running and the treadmill speed at the onset of metabolic acidosis showed that there was a statistically significant difference between the speed at the onset of metabolic acidosis and the chosen optimal speed of running.

There was a significant difference between high and low fitness groups in the selection of the optimal speed of running and the relationship to the onset of metabolic acidosis speed. The congruence between the treadmill speeds of optimal running and the onset of metabolic acidosis were greater for the groups of high fitness. Since a significant difference existed between the male and female high fit groups, and not between the low fit groups, the selection of an optimal speed of running was not affected by sex differences at the low fitness levels.

The selection of an optimal speed of running compared to the speed at the onset of metabolic acidosis was primarily determined by fitness and minimally affected by sex. The higher the onset of metabolic acidosis percentage of maximal oxygen consumption the less the difference between the speed at the onset of metabolic acidosis. The high fitness individuals were more able to subjectively select an optimal speed of running that maximized aerobic metabolism without a significant build up of lactic acid than were the individuals of lower fitness. Individuals of long experience in physical training are better able to utilize perception of effort in decision making about selection of exercise intensity (52). They were more accurate in gauging an optimal pace than were individuals of low fitness. The low fitness individuals tended to vastly overestimate an optimal running pace based upon data of their onset of metabolic acidosis.

Despite considerable research on the topic, the mechanism by which individuals perceive the intensity of exertion during exercise remains unknown. The research suggests that self-awareness of exercise cost is best viewed within a psychophysiological context. It has been proposed that psychophysiological awareness (effort sense) of exercise cost governs the elicitation of maximal endurance performance or in maintaining a given pace, is a cognitive-perceptual process which involves the integration or totality of cues being processed by the exercising organism (52).

A study conducted by Purvis and Cureton (57), following the data collection of this study, found that young men and young women perceived an exercise intensity equal to the onset of metabolic acidosis as 'somewhat hard' on the Borg scale (9). They reasoned that the similar perception of the exercise intensity corresponding to the onset of metabolic acidosis by different individuals makes it possible to prescribe an exercise intensity equivalent to the onset of metabolic acidosis using ratings of perceived exertion.

The whole area of perceived exertion requires much more research and further analysis of the topic is beyond the scope of this study.

<u>The Oxygen Consumption of Optimal Speed Walking and at the Onset of Metabolic Acidosis</u>

Figure 4 contained the mean relative oxygen consumption at the optimal speed of walking and at the onset of metabolic acidosis. The results of the statistical analysis of the relative oxygen consumption at the optimal speed of walking showed no statistically significant difference between fitness groups or between males and females. Regardless of fitness level, males and females tended to select an optimal speed of walking, with a corresponding oxygen consumption, that was similar. The selection of an optimal speed of walking or the relative oxygen consumption at the speed of walking was unaffected by fitness level or sex. In contrast, the statistical analysis of the relative oxygen consumption at the onset of metabolic acidosis revealed that there was a significant difference between high and low fitness groups. High fit individuals had significantly higher relative oxygen consumption levels at the onset of metabolic acidosis than the low fit individuals. There was no significant difference between males and females of similar fitness implying that the difference in the onset of metabolic acidosis was unaffected by sex.

There were statistically significant differences between the relative oxygen consumption at the optimal speed of walking and at the onset of metabolic acidosis within the high fit male group, the high fit female group, and the low fit female group. There was no statistically significant difference between these two measures in the low fit male group. Only the low fit male group demonstrated a relationship between the onset of metabolic acidosis in terms of relative oxygen consumption and the relative oxygen consumption at the optimal speed of walking. Since this relationship between optimal speed of walking and the onset of metabolic acidosis was not reflected in treadmill speed at these measures, and since speed and oxygen consumption are directly related, the significance of this finding is most likely minor.

The results of the statistical analysis for the difference between the relative oxygen consumption at the optimal speed of walking and the the onset of metabolic acidosis showed that there was a statistically significant difference between the oxygen consumption at the optimal speed of walking and the oxygen consumption at the onset of metabolic acidosis.

The findings of relative oxygen consumption parallelled the findings of treadmill speed at the optimal speed of walking and the onset of metabolic acidosis. The significant difference between high and low groups may be attributable to a greater proximity of the optimal speed of walking and the onset of metabolic acidosis for low fitness groups. There existed no statistically significant difference between high fit males and high fit females and between low fit males and low fit females implying no significant sex difference between subjects of similar fitness.

The Oxygen Consumption of Optimal Speed Running and at the Onset of Metabolic Acidosis

Figure 5 contained the mean relative oxygen consumption at the optimal speed of running and at the onset of metabolic acidosis. The results of the statistical analysis of the relative oxygen consumption at the optimal speed of running showed only a significant difference between the high fit males and low fit females. This would suggest that either the selection of an optimal speed of running, and its corresponding oxygen demands, was relatively similar in males or females of high and low fitness or, there was inaccuracy in the selection of an optimal speed of running for some individuals as previously discussed. The statistical analysis of the relative oxygen consumption at the onset of metabolic acidosis showed that there was a significant difference between high and low fitness groups. There was no significant difference between males and females of similar fitness levels.

There were statistically significant differences between the relative oxygen consumption at the optimal speed of running and the onset of metabolic acidosis within both the low fit male and low fit female groups. There was no significant difference between the relative oxygen consumption at the optimal speed of running and the onset of metabolic acidosis within either the high fit male or high fit female groups. In other words, the measured onset of metabolic acidosis and the subjectively determined optimal speed of running, in terms of treadmill speed and relative oxygen consumption, showed no discernible differences, by the statistical treatments employed, for both high fit groups.

The results of the statistical analysis for the difference between the relative oxygen consumption at the optimal speed of running and the onset of metabolic acidosis showed that there was a statistically significant difference between the oxygen consumption at the optimal speed of running and the onset of metabolic acidosis.

As with treadmill speeds for these two variables there was a significant difference between fitness groups. The high fitness individuals were better able to select an optimal speed of running, with a corresponding oxygen consumption, that maximized aerobic metabolism with minimal lactate build up than were low fit individuals. Much of this difference between fitness groups was likely a result of inaccurately perceived levels of exertion by the low fit individuals.

The Selection of the Optimal Speed of Running in Relation to the Onset of Metabolic Acidosis and Fitness Level

The selection of an optimal speed of running by the subjects under study was compared to the treadmill speed at the onset of metabolic acidosis during the progressive intensity exercise test to maximal oxygen consumption. The optimal running speed was expressed as a percentage of the treadmill speed at the onset of metabolic acidosis to determine the extent to which fitness rankings and sex had a bearing on the proximity of these two measures.

Figure 6 illustrated this relationship between the optimal speed of running and the onset of metabolic acidosis as mean data values. All fitness groups, on the average, selected optimal speeds of running that were in excess of the treadmill speeds at the onset of metabolic acidosis. Clearly however, the high fitness groups selected optimal speeds of running that were closer to their onset of metabolic acidosis. Table 3 showed that fifty percent of the high fit males selected an optimal speed of running that was ± 10% of the speed at the onset of metabolic acidosis and that seventy percent of the high fit females chose an optimal speed of running in the same range. In contrast, at least seventy percent of both groups of low fitness selected optimal speeds of running that were in excess of 115% of the treadmill speed at the onset of metabolic acidosis.

Costill et al. (16) and Farrel et al. (32), found that regardless of the competitive level, the highly trained endurance athlete could maintain an average velocity during a marathon which was only slightly above his onset of plasma lactate accumulation (OPLA). Similarly the high fit subjects under study selected optimal speeds of running that were only slightly above, or immediately near, the speed at the onset of metabolic acidosis.

There was no statistically significant difference between the sexes in relation to the selection of an optimal speed of running as compared to the speed at the onset of metabolic acidosis. The proximity of the optimal speeds of running and the onset of metabolic acidosis leads one to hypothesize that the most comfortable speed of running could be used as an effective training stimulus for high fit males or females.

The low fitness individuals appeared to greatly overestimate their optimal speed of running in relation to their onset of metabolic acidosis. This overestimation of optimal running speed further substantiates the role perceived exertion likely plays in the selection of optimal pace. The inability of inactive individuals to accurately gauge their intensity of physical activity necessitates supervision of low fitness individuals at the outset of fitness programs and longer periods of familiarity in the research setting. By increasing the awareness of inactive individuals to more accurately gauge exercise intensities the use of the most comfortable speed of running could also be used as an effective training stimulus for low fit individuals.

Since maximization of energy expenditure is a prime concern of exercise programs for weight reduction, and a common reason for low fit individuals to get involved in an exercise program, a training intensity near the onset of metabolic acidosis should be ideal for maximizing energy expenditure while delaying fatigue.

The Power Output at Maximal Oxygen Consumption

The results of the two way analysis of variance on the power output data at maximal oxygen consumption with the factors being sex; male and female, and fitness; high or low showed that there was no statistically significant difference between fitness groups in power output at maximal oxygen consumption. There was, however, a statistically significant difference between males and females in power output at their maximal oxygen consumption. The males' power output was significantly higher than the females' power output. This was largely due to the natural imbalance of lean body tissue between males and females. The naturally greater percentage of adipose tissue in women has been shown to decrease performance in relatively prolonged weight bearing work such as distance running. The greater amount of adipose tissue which does not contribute to the body's energy producing capacity acts as a burden, and therefore, the ability to perform any given level of work is reduced (17). The consequences being, maximal oxygen consumption was elicited at a lower rate of work, and the pace that could be maintained for a given period of time was negatively affected.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was (1) to determine the optimal speeds of walking and running which were chosen by the subjects as their most comfortable speeds and the steady state oxygen consumption at these speeds during a 6 minute test, and (2) to determine the onset of metabolic acidosis by the respiratory exchange method of a minimum in the ventilatory equivalent for oxygen during a maximal oxygen consumption test.

The first session served as a familiarity one for each subject. Each subject walked and ran on the treadmill at several speeds which served to reduce anxiety associated with the treadmill.

The purpose of session 2 was to subjectively determine (a) the optimal speed of walking, (b) the optimal speed of running, as well as, (c) the steady state oxygen consumption at these speeds. In addition, the percentage of body fat on each subject was estimated using the hydrostatic method.

The third testing session for each subject was the determination of their maximal oxygen consumption and onset of metabolic acidosis represented by the minimum of the ventilatory equivalent of oxygen.

The data collected was subsequently used to divide the 40 subjects into 4 groups based upon sex and fitness which was represented by their percentage of maximal oxygen consumption at the onset of metabolic acidosis. The data of these 4 groups was analyzed by one and two-way analysis of variance.

Conclusions

Within the limitations of this study the following conclusions seemed justifiable:

(1) There was no significant difference in the selection of an optimal speed of walking, or the relative oxygen consumption at that speed, in males and females of high and low fitness levels.

(2) There was a significant difference in the selection of an optimal speed of running, and the relative oxygen consumption at that speed, between the high fit males and the low fit females.

(3) The speed and relative oxygen consumption at the onset of metabolic acidosis was significantly higher in the high fitness groups than the low fitness groups. There was no significant difference between males and females.

(4) The speed and relative oxygen consumption at the optimal speed of walking was significantly below the speed and relative oxygen consumption at the onset of metabolic acidosis.

(5) The speed and relative oxygen consumption at the optimal speed of running was not significantly different from the speed and relative oxygen consumption at the onset of metabolic acidosis in the high fit males or high fit females.

(6) The males' power output at maximal oxygen consumption was significantly higher than the females' power output.

Recommendations for Further Research

More research is necessary to determine the differences in training effectiveness around the onset of metabolic acidosis, the degree of training that can occur to the onset of metabolic acidosis, and what types of training provide the best results.

An additional topic that surfaced from this study, that of perceived exertion, needs to be further researched as to the role it plays in the selection of an optimal pace whether walking, running, cycling swimming or any activity of a physical nature. Perhaps this area of psychophysiology may hold some answers into better training techniques, as to how an athlete may improve after physical abilities have apparently plateaued, or how top-level athletes are able to block out psychological feedback to continue at very high intensity levels.

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APPENDIX A

CONSENT TO UNDERGO TESTING

I ____ hereby agree to volunteer in a study to determine my optimal speeds of walking and running and the onset of metabolic acidosis via respiratory gas analysis during a progressive intensity exercise test.

I understand that I will:

a) Walk and run for a period of six minutes at a speed that I find most comfortable.

b) Undergo the test to determine my body fat by the densitometry method.

c) Perform a maximal oxygen uptake test.

I understand that with any type of exercise there are potential risks and at any time during the test if I experience unusual discomfort I will ask to discontinue the test.

In agreeing to such an examination, I waive any legal recourse against the University of Alberta from any and all claims resulting from this fitness test.

Date: ____________________ Subject: ____________________

(Signature)

Witness: ____________________

APPENDIX B

INSTRUCTIONS TO SUBJECTS FOR TESTING SESSIONS

This study is conducted to determined the relationship between the most comfortable speeds of walking and running and the onset of metabolic acidosis, which is the point at which lactate begins to accumulate in the muscles and blood, which ultimately leads to fatigue. The greater the delay in one's onset of metabolic acidosis with progressive intensity exercise the greater the cardiorespiratory endurance capacity, or in simpler terms, heart and lung fitness.

It is hypothesized that when an individual exceeds his or her optimal speeds of locomotion, whether walking or running, the body is no longer capable of producing energy largely through aerobic means and is forced to a greater degree to utilize anaerobic means to maintain the energy yield. Should this prove to be the case then the optimal endurance training stimulus for the normal individual or athlete should be at or near the optimal speed of locomotion for that individual.

In order to increase the reliability of the metabolic measurements that will be determined in sessions 2 and 3, it is necessary that the following precautions by undertaken by you:

1) Avoid ingesting any foods or nutrients for at least 2 hours prior to your scheduled testing time
2) Avoid vigorous physical activity for at least 2 hours prior to your scheduled testing time.
3) For each of the 3 testing sessions come dressed in shorts, top and running shoes. For the 2nd session a bathing suit and towel are also necessary.

APPENDIX C

INFORMATION SHEET

NAME: ______________________ Age: ___ Yrs. ___ Months

OCCUPATION:

Height (in bare feet): cms.

Weight (with gym strip): kgs.

Training Habits:

DETERMINATION OF BODY FAT BY THE UNDERWATER WEIGHING METHOD

NAME: Sex: Number:

Measurements:

(1) Weight in air =

(2) Vital Capacity (V.C.) = litres x 61.02 = cu. ins.

(3) Residual Volume = 25% or 30% V.C. = cu. ins.

(4) Volume of Gastrointestinal tract (V.G.I.) = 7.01 cu. ins.

(5) Weight in water = $\frac{\text{Chart reading x Belt weight}}{75}$ - belt weight

= lbs.

Calculations:

(6) Total body air (T.B.A.) = V.C. + R.V. + V.G.I. (from above 2,3,4)

= x .0362 = lbs.

(7) True weight in water = weight in water (5) + total body air (6)

= lbs.

(8) Body volume = weight in air (1) - true weight in water (7)

=

(9) Body density = weight in air (1) x density of water at C.

(10) Percent Fat = $\frac{4.570}{\text{Body density (a)}}$ - 4.142 x 100

=

(11) Pounds fat = percent fat (10) x Wt. in air (1)

= lbs.

(12) Fat free weight = weight in air (1) - pounds fat (11)

= lbs.

(13) Fat free weight in kilograms= kgs

CHARACTERISTICS OF THE OPTIMAL WALK

Name: Number:

Age (months): Mass*: lbs. kgs.

Activity: Walking

Optimal Speed: Kmh or m/min

Treadmill Setting (% rpm):

6 Minute Submaximal Walk

Time (Secs)	Heart Rate	VO_2 ml/min	VO_2 ml/kg/min
30			
60			
90			
120			
150			
180			
210			
240			
270			
300			
330			
360			
Steady State			

* With running shoes

CHARACTERISTICS OF THE OPTIMAL RUN

Name: Number:

Age (months): Mass*: lbs. kgs.

Activity: Running

Optimal Speed: Kmh or m/min

Treadmill Setting (% rpm):

6 Minute Submaximal Run

Time (Secs)	Heart Rate	VO_2 ml/min	VO_2 ml/kg/min
30			
60			
90			
120			
150			
180			
210			
240			
270			
300			
330			
360			
Steady State			

* With running shoes

MAXIMAL OXYGEN UPTAKE ON TREADMILL TEST

Name: Number:

Mass: kgs. Age (yrs):

Max. O_2 consumption: (ml/kg/min)

Treadmill speed (% max rpm): grade:

Treadmill Speed: Kmh or m/min

Heart Rate:

Onset of Metabolic Acidosis: (ml/kg/min)

Treadmill speed (% max rpm):

Treadmill speed: Kmh or m/min

Heart Rate:

Percentage of Maximal O_2 Consumption at Onset of Metabolic Acidosis:

APPENDIX D

DETERMINATION OF POWER OUTPUT AT MAX VO_2

Vertical Distance = Sine of angle θ x Distance along incline
= (Sine θ) x (B)

Example:

θ = 2

Sine θ = 0.0349

Speed = 121.7 metres/minute

*Time = 1.0 minute

Subject weight = 75.0 kgs.

B = (121.7 m/min)(1.0) = 121.7 metres

X = (121.7m)(0.0349) = 4.24733 metres

$$\text{Power Output} = \frac{\text{Weight (kgs) x Distance (metres)}}{\text{Time (minutes)}} = \text{kg/metres/min}$$

$$= \frac{75.0 \times 4.24733}{1.0} = 318.550 \text{ kg/metres/min}$$

* Power Output was determined for a time period of 1.0 minutes for all subjects

APPENDIX E

STATISTICAL TREATMENT OF DATA

Table 5

Analysis of Variance of Steady State Optimal Speed Walking

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	720.036	3	240.01	2.52
	3425.179	36	95.14	

$^*p < 0.05$

Table 6

Analysis of Variance of Steady State Optimal Speed Running

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	6982.606	3	2327.54	7.56*
	18064.207	36	307.82	

*p < 0.05

Table 7

Significant Differences Between Groups Using Scheffe Test For the Optimal Speed of Running

		Hi Fit Males 174.61	Lo Fit Males 160.87	Hi Fit Females 752.46	Lo Fit Females 138.20
Hi Fit Males	174.61	0	3.07	7.97	21.53*
Lo Fit Males	160.87		0	1.15	8.35
Hi Fit Females	152.46			0	3.30
Lo Fit Females	138.20				0

*$p < 0.05$

Table 8

Analysis of Variance of the Treadmill Speed at the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	13993.900	3	4664.66	16.52
	10165.223	36	282.37	

$^{*}p < 0.05$

Table 9

Significant Differences Between Groups Using Scheffe Test For the Treadmill Speed at the Onset of Metabolic Acidosis

		Hi Fit Males 164.59	Lo Fit Males 124.12	Hi Fit Females 143.66	Lo Fit Females 116.31
Hi Fit Males	164.59	0	29.00*	7.76	41.28*
Lo Fit Males	124.12		0	6.76	1.08
Hi Fit Females	143.66			0	13.25
Lo Fit Females	116.31				0

*$p < 0.05$

Table 10

Significant Differences Within Groups Using Scheffe Test for the Difference Between the Optimal Speed of Walking and the Onset of Metabolic Acidosis

			ONSET OF METABOLIC ACIDOSIS			
			Hi Fit Males 164.59	Lo Fit Males 124.12	Hi Fit Females 143.66	Lo Fit Females 116.31
OPTIMAL SPEED WALKING	Hi Fit Males	90.01	147.34*			
	Lo Fit Males	87.47		35.58*		
	Hi Fit Females	82.25			99.90*	
	Lo Fit Females	79.21				36.46*

*$p < .05$

Table 11

Significant Differences Within Groups Using Scheffe Test for the Difference Between the Optimal Speed of Running and the Onset of Metabolic Acidosis

			ONSET OF METABOLIC ACIDOSIS			
			Hi Fit Males 164.59	Lo Fit Males 124.12	Hi Fit Females 143.66	Lo Fit Females 116.31
OPTIMAL SPEED WALKING	Hi Fit Males	174.51	0.24			
	Lo Fit Males	160.87		3.27*		
	Hi Fit Females	152.46			0.19	
	Lo Fit Females	138.66				1.16

*p <.05

Table 12

Analysis of Variance of the Relative Oxygen Consumption at Optimal Walk Speed

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	16.914	3	5.64	0.74
	272.702	36	7.58	

$*p < 0.05$

Table 13

Analysis of Variance of the Relative Oxygen Consumption at Optimal Run Speed

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	168.387	3	56.13	4.71*
	429.414	36	11.93	

*$p < 0.05$

Table 14

Significant Differences Between Groups Using Scheffe Test For the Relative Oxygen Consumption at the Optimal Speed of Running

		Hi Fit Males 33.40	Lo Fit Males 30.63	Hi Fit Females 29.65	Lo Fit Females 27.71
Hi Fit Males	33.40	0	3.22	5.89	13.57*
Lo Fit Males	30.63		0	0.40	3.57
Hi Fit Females	29.65			0	1.58
Lo Fit Females	27.71				0

*$p < 0.05$

Table 15

Analysis of Variance of the Relative Oxygen Consumption at the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Groups	851.401	3	283.80	25.53*
	400.152	36	11.23	

*$p < 0.05$

Table 16

Significant Differences Between Groups Using Scheffe Test For the Relative Oxygen Consumption at the Onset of Metabolic Acidosis

		Hi Fit Males 30.40	Lo Fit Males 19.51	Hi Fit Females 27.16	Lo Fit Females 20.20
Hi Fit Males	30.40	0	53.35*	4.72	46.80*
Lo Fit Males	19.51		0	26.33*	0.21
Hi Fit Females	27.16			0	21.79
Lo Fit Females	20.20				0

*$p < 0.05$

Table 17

Significant Differences Within Groups Using Scheffe Test for the Difference Between the Relative Oxygen Consumption at the Optimal Speed of Walking and at the Onset of Metabolic Acidosis

			ONSET OF METABOLIC ACIDOSIS			
			Hi Fit Males 30.40	Lo Fit Males 19.51	Hi Fit Females 27.16	Lo Fit Females 20.20
OPTIMAL SPEED WALKING	Hi Fit Males	14.49	135.43*			
	Lo Fit Males	14.28		14.63		
	Hi Fit Females	12.98			107.58*	
	Lo Fit Females	13.23				25.99*

*p < .05

Table 18

Significant Differences Within Groups Using Scheffe Test for the Difference Between the Relative Oxygen Consumption at the Optimal Speed of Running and at the Onset of Metabolic Acidosis

			ONSET OF METABOLIC ACIDOSIS			
			Hi Fit Males 30.40	Lo Fit Males 19.51	Hi Fit Females 27.16	Lo Fit Females 20.20
OPTIMAL SPEED WALKING	Hi Fit Males	33.40	3.91			
	Lo Fit Males	30.63		53.66*		
	Hi Fit Females	29.65			2.69	
	Lo Fit Females	27.71				24.48*

*p < .05

Table 19

Analysis of Variance of the Difference Between the Treadmill Speed at Optimal Walking and the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Speed	55377.800	1	55377.800	292.940*
Groups	9245.310	3	3081.770	16.302*
Speed/Groups	516.419	3	1721.400	9.106*
	13611.000	72	189.42	

*$p < 0.05$

Table 20

Significant Differences Between Groups Using Scheffe Test For the Differences Between the Optimal Speed of Walking and Onset of Metabolic Acidosis

	Hi Fit Males 127.30	Lo Fit Males 105.80	Hi Fit Females 112.96	Lo Fit Females 98.13
Hi Fit Males 127.30	0	8.15*	3.63*	15.00*
Lo Fit Males 105.80		0	0.90	1.04
Hi Fit Females 112.96			0	3.88*
Lo Fit Females 98.13				0

*$p < 0.05$

Table 21

Analysis of Variance of the Difference Between the Treadmill Speed at Optimal Running and the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Speed	7358.000	1	7358.00	24.911*
Groups	18152.000	3	6050.066	20.485*
Speed/Groups	251.900	3	839.667	2.843*
	21267.000	72	295.375	

*$p < 0.05$

Table 22

Significant Differences Between Groups Using Scheffe Test For the Differences Between the Optimal Speed of Running and Onset of Metabolic Acidosis

		Hi Fit Males 169.60	Lo Fit Males 142.50	Hi Fit Females 148.06	Lo Fit Females 127.63
Hi Fit Males	169.60	0	8.29*	5.24*	19.88*
Lo Fit Males	142.50		0	0.35	2.50
Hi Fit Females	148.06			0	4.71*
Lo Fit Females	127.63				0

*$p < 0.05$

Table 23

Analysis of Variance of the Difference Between Relative Oxygen Consumption at Optimal Speed of Walking and the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Speed	2089.990	1	2089.990	178.957*
Groups	364.996	3	121.665	10.418*
Speed/Groups	347.754	3	115.918	9.926*
	840.871	72	11.679	

*$p < 0.05$

Table 24

Significant Differences Between Groups Using Scheffe Test For the Difference Between the Relative Oxygen Consumption at Optimal Walk Speed and the Onset of Metabolic Acidosis

		Hi Fit Males 21.75	Lo Fit Males 16.90	Hi Fit Females 20.07	Lo Fit Females 16.72
Hi Fit Males	21.75	0	6.71*	0.80	7.22*
Lo Fit Males	16.90		0	2.88*	0.002
Hi Fit Females	20.07			0	3.21*
Lo Fit Females	16.72				0

*$p < 0.05$

Table 25

Analysis of Variance of the Difference Between the Relative Oxygen Consumption at Optimal Speed of Running and the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Speed	727.207	1	727.207	63.113*
Groups	770.773	3	256.924	22.298*
Speed/Groups	249.027	3	83.009	7.204*
	829.609	72	11.522	

*$p < 0.05$

Table 26

Significant Differences Between Groups Using Scheffe Test For the Difference Between the Relative Oxygen Consumption at Optimal Run Speed and the Onset of Metabolic Acidosis

		Hi Fit Males 31.90	Lo Fit Males 25.07	Hi Fit Females 28.41	Lo Fit Females 23.96
Hi Fit Males	31.90	0	13.50*	3.53*	18.22*
Lo Fit Males	25.07		0	3.22*	0.36
Hi Fit Females	28.41			0	5.73*
Lo Fit Females	23.96				0

*$p < 0.05$

Table 27

Analysis of Variance of the Optimal Speed of Running as a Percentage of the Speed at the Onset of Metabolic Acidosis

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Sexes	82.250	1	82.250	0.316
Groups	4761.000	1	4761.000	18.285*
Sexes/Groups	9.375	1	9.375	0.0360
	9383.130	37	253.598	

*$p < 0.05$

Table 28

Analysis of Variance of Power Output at Maximal Oxygen Consumption

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Sex	1,723,590	1	1,723,590	24.998*
Fitness Levels	75,210	1	75,210	1.102
Sex/Fitness Levels	94,640	1	94,640	1.387
	2,551,170	37	68,950	

$^{*}p < 0.05$

APPENDIX F

RAW DATA

Table 29 - Characteristics of High Fit Male Subjects

Subject Number	Age (Years)	Height (cms)	Mass (kgs)	Percent Body Fat	Lean Body Weight (kgs)
1	21.67	180	66	11.9	58.1
2	20.75	185	87.5	12.5	78.4
3	21.67	183	69.2	7.5	63.7
4	23.08	173	73.9	14.9	61.6
5	21.08	187	83.2	8.9	74.9
6	21.83	185	77.6	5.6	72.6
7	22.75	191	85.5	12.0	74.4
8	21.67	178	73.4	3.2	70.7
9	28.67	175	73.0	9.7	67.5
10	20.17	179	70.5	4.0	67.6
MEAN	22.33	182	76.0	9.0	68.9

Table 30 - Characteristics of Low Fit Male Subjects

Subject Number	Age (Years)	Height (cms)	Mass (kgs)	Percent Body Fat	Lean Body Weight (kgs)
11	20.08	183	74.5	10.3	65.9
12	35.75	170	94	18.2	73.3
13	22.42	172.7	71.4	12.5	60.8
14	22.0	178	72.3	12.3	62.6
15	21.58	182.9	72.1	8.2	66.1
16	23.83	188	101.0	20.8	79.9
17	23.75	193	98.5	12.8	85.3
18	22.25	179	70.8	15.8	59.4
19	20.92	180.3	80.5	21.6	63.1
20	18.25	162.5	62.0	17.4	51.1
MEAN	23.08	178.9	79.7	15.0	66.7

Table 31 - Characteristics of High Fit Females

Subject Number	Age (Years)	Height (cms)	Mass (kgs)	Percent Body Fat	Lean Body Weight (kgs)
21	19.92	167.6	54.4	10.9	44.9
22	23.50	175.3	64.0	20.4	50.7
23	19.08	160.0	52.5	23.9	40.0
24	20.33	162.5	72.3	32.7	48.6
25	22.33	172.7	59.7	21.2	47.0
26	25.83	162.6	65.7	26.2	47.7
27	25.0	172.7	68.3	13.5	58.4
28	21.75	162.5	57.0	13.2	46.2
29	21.33	[illegible]	59.2	22.4	45.5
30	19.58	[illegible]	66.5	18.6	54.1
MEAN	21.87	[illegible]	62.0	20.3	48.3

Table 32 - Characteristics of Low Fit Females

Subject Number	Age (Years)	Height (cms)	Mass (kgs)	Percent Body Fat	Lean Body Weight (kgs)
31	19.33	174.6	63.4	23.5	48.5
32	23.33	170.2	57.9	18.3	46.7
33	18.33	165.0	54.0	22.5	41.7
34	21.58	162.6	72.0	24.5	54.2
35	22.0	165.0	48.0	19.4	44.4
36	19.5	162.5	59.5	17.0	45.5
37	18.33	175.0	62.0	19.8	48.8
38	18.25	160.0	49.0	25.3	36.0
39	22.17	162.5	62.5	26.5	45.9
40	21.33	171.5	62.9	19.5	50.6
MEAN	20.42	166.9	59.1	21.6	46.3

Table 33 - Characteristics of Optimal Speed Walking in High Fit Males

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
1	106.2	6.4	1102	16.7	120
2	97.7	5.9	1344	15.4	–
3	90.2	5.4	1090	15.8	112
4	86.4	5.2	1050	14.2	95
5	75.2	4.5	932	11.2	86
6	75.2	4.5	1040	13.4	94
7	82.7	5.0	1129	13.2	90
8	93.9	5.6	1065	14.5	96
9	106.2	6.4	1263	17.3	104
10	86.4	5.2	930	13.2	96
MEAN	90.0	5.4	1095	14.5	99

Table 34 - Characteristics of Optimal Speed Walking in Low Fit Males

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
11	90.2	5.4	1244	16.7	105
12	63.0	3.8	846	9.0	98
13	86.4	5.2	1214	17.0	112
14	82.7	5.0	854	11.8	110
15	97.7	5.9	1321	18.3	96
16	82.7	5.0	1276	12.6	98
17	90.2	5.4	595	6.4	96
18	97.7	5.9	1172	16.6	115
19	90.2	5.4	1290	16.1	–
20	93.9	5.6	1134	18.3	130
MEAN	87.5	5.2	1095	14.3	106.6

Table 35 - Characteristics of Optimal Speed Walking in High Fit Females

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
21	97.7	5.9	608	11.2	116
22	75.2	4.5	723	11.3	88
23	67.0	4.0	491	9.4	90
24	82.7	5.0	894	12.4	91
25	82.7	5.0	884	14.8	–
26	90.2	5.4	1195	18.2	112
27	90.2	5.4	954	14.0	98
28	75.2	4.5	942	16.5	107
29	78.9	4.7	616	10.4	99
30	82.7	5.0	772	11.6	107
MEAN	82.3	4.9	807.9	13.0	100.9

Table 36 - Characteristics of Optimal Speed Walking in Low Fit Females

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
31	75.2	4.5	735	11.6	118
32	82.7	5.0	776	13.4	86
33	78.9	4.7	697	12.9	88
34	97.7	5.9	978	13.6	113
35	75.2	4.5	739	15.4	120
36	71.1	4.3	639	10.7	105
37	86.4	5.2	924	14.9	104
38	67.0	4.0	632	12.9	115
39	75.2	4.5	837	13.4	102
40	82.7	5.0	847	13.5	92
MEAN	79.2	4.8	780.4	13.2	104.3

Table 37 - Characteristics of Optimal Speed Running in High Fit Males

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
1	175.6	10.5	2343	35.3	133
2	175.6	10.5	2490	28.5	160
3	167.8	10.1	2255	32.6	152
4	167.8	10.1	2808	38.0	160
5	156.0	9.4	2530	30.0	165
6	179.2	10.8	2780	35.8	147
7	163.8	9.8	2340	27.9	134
8	171.8	10.3	2594	35.3	164
9	213.0	12.8	2774	38.0	155
10	175.6	10.5	2298	32.6	-
MEAN	174.6	10.5	2521	33.4	152

Table 38 - Characteristics of Optimal Speed Running in Low Fit Males

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
11	171.7	10.3	2041	27.4	140
12	182.9	11.0	2800	29.5	143
13	167.8	10.1	2556	35.8	156
14	125.8	7.5	1830	25.3	144
15	175.6	10.5	2408	33.4	138
16	159.7	9.6	2912	28.8	152
17	145.7	8.7	2400	24.3	145
18	163.8	9.8	2523	35.7	154
19	159.7	9.6	2568	31.9	150
20	156.0	9.4	2120	34.2	164
MEAN	160.9	9.7	2416	30.6	148.6

Table 39 - Characteristics of Optimal Speed Running in High Fit Females

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
21	159.7	9.6	1598	29.4	158
22	156.0	9.4	2010	31.4	158
23	130.0	7.8	1379	26.3	-
24	145.7	8.7	2062	28.5	133
25	141.9	8.5	1803	30.2	-
26	167.8	10.1	2328	35.4	160
27	175.6	10.5	2150	31.5	152
28	138.2	8.3	1091	29.7	-
29	141.9	8.5	1576	26.6	149
30	167.8	10.1	1828	27.5	160
MEAN	152.5	9.1	1783	29.7	152

Table 40 - Characteristics of Optimal Speed Running in Low Fit Females

Subject Number	OPTIMAL SPEED		OXYGEN CONSUMPTION		STEADY STATE HEART RATE
	metres/min	km/hr	ml/min	ml/kg/min	
31	138.2	8.3	1800	28.4	170
32	145.7	8.7	146.5	25.3	133
33	167.8	10.1	1764	32.7	150
34	163.8	[illegible]	2088	29.0	164
35	121.7	7.3	1286	26.8	132
36	145.7	8.7	1588	26.7	152
37	138.2	8.3	1612	26.0	154
38	121.7	7.3	1311	26.8	165
39	149.0	8.9	2025	32.4	168
40	163.8	9.8	1440	23.0	-
MEAN	145.6	8.7	1638	27.7	154.2

Table 41 - Characteristics of the Maximal Oxygen Consumption in High Fit Males

Subject Number	TREADMILL SPEED metres/min	TREADMILL SPEED km/hr	GRADE (Degrees)	OXYGEN CONSUMPTION ml/min	OXYGEN CONSUMPTION ml/kg/min	HEART RATE	POWER OUTPUT AT MAX VO_2
1	241.1	14.5	5.24	3641	55.4	184	832.2
2	229.6	13.8	3.71	3753	42.4	184	745.3
3	241.1	14.5	6.12	3672	53.2	205	1017.7
4	255.1	15.3	4.80	3648	49.1	196	904.9
5	213.0	12.8	5.68	3514	41.6	198	1004.8
6	261.2	15.7	4.80	4126	53.2	189	972.9
7	241.1	14.5	6.12	4001	46.7	192	1257.5
8	247.8	14.9	6.12	3532	48.8	183	1109.5
9	292.9	17.6	3.71	3793	50.7	189	793.3
10	255.1	15.3	4.80	3007	42.4	198	863.3
MEAN	247.8	14.9	5.11	3669	48.4	192	950.1

Table 42 - Characteristics of the Maximal Oxygen Consumption in Low Fit Males

Subject Number	TREADMILL SPEED metres/min	TREADMILL SPEED km/hr	GRADE (Degrees)	OXYGEN CONSUMPTION ml/min	OXYGEN CONSUMPTION ml/kg/min	HEART RATE	POWER OUTPUT AT MAX VO_2
11	255.1	15.3	4.80	3663	49.1	188	912.2
12	213.0	12.8	0.00	3332	35.0	158	0.0
13	197.9	11.9	5.24	3358	48.1	182	739.0
14	241.1	14.5	4.80	3050	42.2	198	836.7
15	255.1	15.3	[illegible].24	3637	48.8	184	961.9
16	241.1	14.5	4.80	4474	44.3	198	1168.9
17	213.0	12.8	3.71	3795	38.7	186	778.4
18	226.6	13.6	4.80	2989	42.4	196	770.1
19	255.1	15.3	4.80	3376	41.3	191	985.7
20	221.1	13.3	3.71	2967	48.2	183	508.3
MEAN	231.9	13.9	4.77	3464	43.8	186	851.3

Table 43 - Characteristics of the Maximal Oxygen Consumption in High Fit Females

Subject Number	TREADMILL SPEED		GRADE	OXYGEN CONSUMPTION		HEART	POWER OUTPUT
	metres/min	km/hr	(Degrees)	ml/min	ml/kg/min	RATE	AT MAX VO_2
21	226.6	13.6	3.71	2487	44.8	187	457.3
22	241.1	14.5	0.00	2705	43.3	–	0.0
23	197.7	11.9	3.71	1975	37.2	194	385.1
24	213.0	12.8	4.80	2458	34.0	194	739.2
25	190.8	11.4	3.71	2305	38.7	194	422.6
26	255.1	15.3	3.71	2967	45.5	196	621.8
27	221.0	13.3	4.80	2976	44.1	186	724.0
28	226.6	13.6	0.00	2200	38.1	182	0.0
29	213.0	12.8	3.71	2284	39.0	182	467.8
30	226.0	13.6	3.71	2950	44.0	–	559.1
MEAN	221.2	13.3	3.98	2531	39.9	189	547.1

Table 44 - Characteristics of the Maximal Oxygen Consumption in Low Fit Fema[illegible]

Subject Number	TREADMILL SPEED		GRADE	OXYGEN CONSUMPTION		HEART	POWER OUTPUT
	metres/min	km/hr	(Degrees)	ml/min	ml/kg/min	RATE	AT MAX VO_2
31	213.0	12.8	0.00	2097	32.6	187	0.0
32	255.1	15.3	4.80	2539	43.8	188	709.0
33	221.0	13.3	4.80	2277	43.0	190	512.8
34	213.0	12.8	5.24	2620	36.4	198	802.1
35	197.7	11.9	3.23	1736	36.2	200	306.5
36	226.6	13.6	5.24	2381	41.4	-	705.1
37	241.1	14.5	0.00	2467	39.2	-	0.0
38	167.8	10.1	6.12	1768	36.0	206	501.6
39	182.9	11.0	3.71	2192	34.8	182	424.1
40	197.7	11.9	3.71	2596	40.3	180	461.4
MEAN	211.6	12.7	4.61	2267	34.8	191	560.3

Table 45 - Characteristics of the Onset of Metabolic Acidosis in High Fit Males

Subject Number	TREADMILL SPEED metres/min	km/hr	OXYGEN CONSUMPTION ml/min	ml/kg/min	HEART RATE	PERCENTAGE OF MAX VO_2	OPTIMAL RUN SPEED AS PERCENTAGE OF O.M.A. SPEED
1	152.3	9.1	2013	30.7	128	55.4	115.3
2	159.7	9.6	2287	25.8	149	60.8	110.0
3	182.9	11.0	2458	35.6	158	67.0	109.0
4	167.8	10.1	2598	34.9	156	71.2	100.0
5	152.3	9.1	2283	27.0	151	64.9	102.4
6	152.3	9.1	2423	31.2	144	58.6	117.7
7	182.9	11.0	2621	30.6	151	65.5	89.6
8	175.6	10.5	2350	32.5	154	66.6	97.8
9	167.8	10.1	2171	29.0	139	57.2	126.9
10	152.3	9.1	1896	26.7	1[illegible]	63.0	115.3
MEAN	164.6	9.9	2310	30.4	146	63.0	108.4

Table 46 - Characteristics of the Onset of Metabolic Acidosis in Low Fit Males

Subject Number	TREADMILL SPEED		OXYGEN CONSUMPTION		HEART RATE	PERCENTAGE OF MAX $\dot{V}O_2$	OPTIMAL RUN SPEED AS PERCENTAGE OF O.M.A. SPEED
	metres/min	km/hr	ml/min	ml/kg/min			
11	167.8	10.1	1994	26.9	142	54.8	102.3
12	121.7	7.3	1750	18.3	124	52.3	150.3
13	121.7	7.3	1391	19.9	121	41.4	137.9
14	121.7	7.3	1377	19.1	134	45.3	103.4
15	121.7	7.3	1382	18.5	113	37.9	144.3
16	121.7	7.3	2151	21.3	128	48.1	131.2
17	106.2	6.4	1597	16.3	107	42.1	137.2
18	138.2	8.3	1438	20.4	128	48.1	118.5
19	106.2	6.4	1226	15.0	114	36.3	150.4
20	114.3	6.9	1190	19.4	110	40.2	136.5
MEAN	124.1	7.4	1550	19.5	122	44.7	131.2

Table 47 - Characteristics of the Onset of Metabolic Acidosis in High Fit Females

Subject Number	TREADMILL SPEED		OXYGEN CONSUMPTION		HEART RATE	PERCENTAGE OF MAX VO_2	OPTIMAL RUN SPEED AS PERCENTAGE OF O.M.A. SPEED
	metres/min	km/hr	ml/min	ml/kg/min			
21	167.8	10.1	1561	28.1	146	62.7	95.2
22	152.3	9.1	1889	30.2	138	69.7	102.4
23	121.7	7.3	1263	23.8	144	62.6	106.8
24	138.2	8.3	1620	22.4	130	65.9	105.4
25	130.0	7.8	1581	26.5	152	68.5	109.2
26	138.2	8.3	1938	29.7	154	65.3	121.4
27	159.7	9.6	1834	27.2	142	61.7	110.0
28	152.3	9.1	1809	31.3	144	82.2	90.7
29	138.2	8.3	1493	25.5	134	65.4	102.7
30	138.2	8.3	1785	26.9	156	60.6	121.4
MEAN	143.7	8.6	1677	27.2	144	66.5	106.5

Table 48 - Characteristics of the Onset of Metabolic Acidosis in Low Fit Females

Subject Number	Treadmill Speed		Oxygen Consumption		Heart Rate	Percentage of Max VO_2	Optimal Run Speed as Percentage of O.M.A. Speed
	metres/min	km/hr	ml/min	ml/kg/min			
31	90.2	5.4	806	12.5	113	38.3	153.2
32	152.3	9.1	1463	25.3	134	57.8	95.7
33	114.3	6.9	1265	35.0	129	58.1	146.8
34	138.2	8.3	1454	20.2	132	55.1	118.5
35	121.7	7.3	960	20.0	126	55.2	100.0
36	121.7	7.3	1277	22.2	139	53.6	119.7
37	121.7	7.3	1226	19.5	120	49.7	113.6
38	90.2	5.4	894	18.2	141	[illegible]	134.9
39	90.2	5.4	1037	16.5	122	47.4	165.2
40	130.0	7.8	1456	22.6	129	56.1	126.0
MEAN	117.0	7.0	1194	20.1	129	52.2	127.4