THE RELATIONSHIP BETWEEN STRIDE LENGTH AND PLASMA LACTATE ACCUMULATION IN HIGHLY TRAINED DISTANCE RUNNERS

A Thesis

by

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ABSTRACT

THE RELATIONSHIP BETWEEN STRIDE LENGTH AND PLASMA LACTATE ACCUMULATION IN HIGHLY TRAINED DISTANCE RUNNERS. (May 1985)

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The purpose of this study was to determine the relationship between stride length measures and plasma lactate accumulation at two relative and submaximal running intensities. The subject sample consisted of 10 college aged male distance runners from Appalachian State University. Seven of the runners were on the cross country and track teams at the university and three were highly trained distance runners but were not on the track or cross country teams at Appalachian State University. Each subject was required to make two visits to the Human Performance Laboratory. On the first visit each subject was run to exhaustion on the treadmill and gas analysis was done during the run to determine maximal oxygen uptake. During the second session each runner was required to complete two submaximal runs on the treadmill. The intensity of the submaximal runs were 70 and 85 percent of the aerobic capacity. Stride length was determined during each of the submaximal runs, and blood samples were taken 5 minutes following each run and analyzed for plasma lactate concentration. Maximal oxygen uptake was measured directly using a Beckman MMI Metabolic Cart.

Pearson Product Correlations revealed several significant correlations between the relative stride length parameters and plasma lactate accumulation during the submaximal runs. Significant correlations were found between plasma lactate accumlation while running at 70 percent of the aerobic capacity and the following variables: the leg length to stride length ratio at the running intensity of 70 percent of the aerobic capacity, the height to stride length, and the leg length to stride length ratios at the running intensity of 85 percent of the aerobic capacity. A significant correlation was also found between plasma lactate accumulation and the height to stride length ratio while running at 85 percent of the aerobic capacity.

Two relatively high but not significant correlations were also found in the present study. The correlation between plasma lactate accumlation and the height to stride length ratio at the running intensity of 70 percent of the aerobic capacity was approaching significance but was nonsignificant at the 0.05 level of confidence. The correlation between plasma lactate accumulation and the leg length to stride length ratio at the running intensity of 85 percent of the aerobic capacity was also fairly high but nonsignificant.

The findings of the present study indicate that fatigue and perceived exertion may play a major role in determining the stride characteristics of highly trained distance runners.

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The author would also like to gratefully acknowledge the following individuals: Mr. Bob Pollock for his cooperation during this study and for his consent to let the track and cross country runners at Appalachian State University participate in this study, Mr. Mark T. Harris for developing the "Treadwork" program used to analyze stride length and treadmill speed, Mr. Don Evitt and Ms. Kathy Foster for their help in the collectiuon of data, and the 10 distance runners who generously contributed their free time to participate in this study.

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CHAPTER 1

INTRODUCTION

The popularity of long distance running has grown at an incredible rate over the past decade. Distance running has grown as a spectator sport, as well as a participatory activity. Over 15 thousand runners participated in the 1983 New York City Marathon which was nationally and internationally televised. This group of athletes consisted of distance runners of various abilities. There were the 5 hour marathoners, the 3 hour marathoners, and the elite distance runners that could run the entire 26.2 miles at a pace just under 5 minutes per mile. The world record for the marathon now stands at 2 hours, 8 minutes and 5 seconds. The existing world record for the 10 kilometer distance is 27 minutes and 13.81 seconds. The average paces for these world record performances were 4 minutes and 53.4 seconds per mile, and 4 minutes and 23.4 seconds per mile for the marathon and 10 kilometers distances respectively. These and other outstanding performances by elite long distance runners have intrigued exercise physiologists for the last half of this century.

Indeed, a vast amount of research has been done involving the biochemical processes and the physiological characteristics of highly competitive distance runners. Among the most important manifestations exhibited by elite long distance runners are: high percentages of slow twitch muscle fibers, enhanced cardiac outputs resulting from left ventricular hypertrophy with normal wall thickness, large aerobic capacities and abnormally high arterio-venous differences during muscular work. Lastly, and probably most importantly, there is an enhancement in muscle respiratory capacity with concurrent increases in the ability to oxidize pyruvate, fatty acids, and ketones. The enhancement of muscle respiratory capacity is a result of an increase in muscle mitochondria, number and size as well as an increase in mitochondrial enzyme concentrations (Costill, Fink & Pollock, 1976; Holloszy, Rennie, Hickson, Conlee & Hogberg, 1977).

All of the biochemical and physiological adaptations listed above are involved in controlling the onset of fatigue. First, these factors interact and allow the distance runner to utilize a high percentage of fatty acids for energy production (resynthesis of adenosine triphosphate) during intense exercise, which in turn, has a glycogen sparing effect. Secondly, the aforementioned physiologcial and biochemical characteristics enable the elite long distance runner to run at a high percentage of the aerobic capacity without the accumulation of high concentrations of plasma lactate (Costill, Gollnick, Jansson, Saltin & Stein, 1973; Farrell, Wilmore, Coyle, Billing & Costill, 1979). The ability to run at a high percentage of one's aerobic capacity without the accumulation of large amounts of plasma lactate, or the depletion of muscle and liver glycogen is crucial to long distance running performance.

Although the physiological and biochemical characteristics inherent in highly trained distance runners are well understood and substantiated, the effect of stride length on distance running performance still remains a controversial issue. Some researchers have concluded that stride length is an important variable when distance running performance is considered. The runners that demonstrated stride lengths that were closely related to their leg lengths and total body heights performed better than their less skilled counterparts who tended to use strides that were not representative of their leg lengths or total body heights (Nelson, Brooks & Pike, 1976; Cavanagh, Pollock & Landa, 1977). Research also exists that indicates that stride length has little if any effect on distance running performance (Cavanagh & Williams, 1982). The conclusions of these studies indicate that the effect of stride length on distance running performance is still an unanswered question. More specifically, the effect of stride length in controlling the onset of plasma lactate accumulation is an important issue that needs to be clarified.

Statement of Problem

The most recent research has indicated that the onset of plasma lactate accumulation is highly correlated with distance running performance. A large volume of research has been done recently in an attempt to determine the physiological and biochemical correlates that are involved in controlling the onset of plasma lactate accumulation. Throughout the literature there is very little conclusive research dealing with the relationship between stride length parameters and plasma lactate accumulation at submaximal running intensities. The present study attempted to determine the relationship between relative stride length measures and plasma lactate accumulation at running intensities of 70 and 85 percent of the subject's aerobic capacity.

Purpose of Study

The purpose of this study was to determine the relationships that exist between plasma lactate accumulation and stride length expressed as a percentage of leg length and total body height while running at 70 and 85 percent of the subject's maximal oxygen uptake.

Hypothesis

The hypothesis of the present study was that there were significant correlations between plasma lactate accumulation and the following variables: stride length in relation to leg length and stride length expressed as a percentage of total body height at the relative running intensities of 70 and 85 percent of the runner's aerobic capacity. Significant correlations were also predicted between stride length and leg length and total body height. Nonsignificant correlations were expected between stride length and plasma lactate accumulation at both running intensities, since simple stride length measures do not take into account leg length or total body height.

Null Hypothesis

The null hypothesis was tested to determine if significant correlations existed between plasma lactate accumulation and stride length expressed as a percentage of leg length and total body height at both of the relative running intensities. The null hypothesis was tested to determine if significant correlations could be identified between stride length and selected anthropometric measures.

Delimitations of Study

The subjects that participated in this study were 10 highly trained long distance runners. Each subject was required to make two visits to the Human Performance Laboratory. On the first day of testing each subject was administered a metabolic stress test using the Bruce Graded Exercise Protocol to determine maximal oxygen uptake. The second testing session consisted of two submaximal treadmill runs of 70 and 85 percent of the subject's aerobic capacity. Time between heel strikes and treadmill speed were monitored during each of the submaximal runs. Blood samples were also drawn at rest and after each of the submaximal runs.

The subjects chosen to participate in the present study were highly trained long distance runners. A highly trained homogeneous group was chosen to help eliminate the high variability in training habits and levels of conditioning that may have existed in a more heterogeneous population.

Expired air was analyzed every 30 seconds throughout the metabolic stress test. Each subject was equipped with a mouthpiece, one-way air valve, noseclip, supporting headgear, and was attached to a Beckman MMI Metabolic Cart. Each subject was connected to the metabolic cart during the entire maximal treadmill run and the highest oxygen consumption achieved was recorded as the subject's aerobic capacity. The metabolic cart was calibrated before each subject was administered the stress test. Heart rate was also monitored using an Exersentry Heart Rate Monitor

During both of the submaximal runs each subject was equipped with the breathing apparatus again and connected to the metabolic cart. Gas samples were analyzed every 30 seconds and the treadmill speed was slowly increased until the specific running intensity was achieved. Once the runners sustained the target oxygen consumption of 90 seconds the breathing apparatus was removed and the runner was required to run for an additional 5 minutes. Heart rate was monitored throughout the submaximal testing to assure that the workload remained constant after the headgear and breathing apparatus were removed. The headgear and breathing devices were removed before stride length measurements were taken to allow the runners to move as naturally and as freely as possible without the interference of the mouthpiece, supporting headgear, and the low resistance tubing. The 5 minute run succeeding the removal of the breathing apparatus was administered to assure that a steady state had been reached before any stride length data were collected.

Stride length was measured by determining the time between heel strikes and multiplying this value by the treadmill speed expressed in inches per second. To determine time between heel strikes a switchmat was embedded in the surface of the treadmill and coaxial wire was used to attach the switchmat to an Analog to Digital (A to D) converter which was connected to a Commodore Pet 4032 Micro-Computer. A specially prepared computer program calculated the time between foot strikes (switch closure) to the nearest 0.01 of a second. The method for determining treadmill speed was also computerized. A microswitch was attached beneath the treadmill and close to the treadmill surface.

Coaxial wire again was used to connect the microswitch to the A to D converter. A small piece of copper metal was glued to the treadmill belt to activate the microswitch closure. The computer program also read the time between switch closures to the nearest 0.01 of a second which was used to calculate treadmill speed.

A balance beam type medical scale was used to measure each subject's height and weight and a Gulick Measuring Tape was used to measure the runner's trochanter height. Body height and weight were measured and the weight of the running shoes and clothing were included in the total body weight and the extra height of the running shoes was also added to the total body height. Leg length measurements were also taken with shoes on, and the same individual measured each subject's trochanter height to ensure that the measuring technique was constant and did not vary between subjects. Each subject's leg length and total body height were entered into the computer and the specially prepared computer program automatically calculated stride length in relation to leg length and total body height. Again, these techniques assured accurate and efficient manipulation of the raw data, and minimized the chance of error.

Blood samples were drawn three different times during the submaximal testing: at rest following a 5 minute rest period, 5 minutes following the submaximal run at 70 percent of the aerobic capacity, and 5 minutes after the run at 85 percent of the subject's maximal oxygen uptake. A laboratory technician was present to draw blood and the blood was drawn into vacutiners containing sodium flouride. The blood was then spun down in a centrifuge to separate the hematocrit from the plasma and was immediately placed on ice. The plasma was then analyzed for lactate concentration using a Yellow Springs Instruments Lactate Analyzer. The above procedures for drawing and analyzing the blood for plasma lactate concentration were meticulously controlled to assure accurate and consistent results.

Limitations of Study

There are two major limitations in the present study. The first limitation was that the resting plasma lactate measures varied among the runners in this study. These differences in the resting plasma lactate concentrations may have affected the performance capacities of the subjects. The runners that had the higher resting plasma lactate concentrations may have been more fatigued by the previous day's workout, which in turn, would have affected the runners performance during the testing procedures in the present study. The resting plasma lactate concentrations could have affected the accumulation of plasma lactate and the stride habits of the athletes at both relative running intensities.

Another limitation of the present study was that the subjects were all tested at different times throughout the day. To avoid interfering with their training schedule all of the subjects were tested between 6:30 a.m. and 12:30 p.m. on two consecutive Mondays. Recent research has indicated that circadian rhythms may affect the performance capacities of various athletes. The studies have indicated that the physiologcial and biochemical processes may not become fully operational until two to three hours after an individual has been awake (Astrand & Rodhal, 1976; Reilly, Robinson & Minors, 1984). The findings of these studies indicate that the subjects in the present study that were tested in the early morning hours could have been at a distinct physiological disadvantage. The early morning subjects may not have had full use of their physiological capacities, which in turn, would have affected the accumulation of plasma lactate and stride habits at both of the relative running intensities.

Definition of Terms

Stride Length - Stride length is the distance covered between toe-off with one foot and the heel strike with the opposite foot.

Stride Length in Relation to Leg Length - Stride length in relation to leg length is expressed as a ratio, and this ratio is derived by dividing leg length by stride length. The quotient from this calculation is the stride length to leg length ratio.

Stride Length in Relation to Total Body Height - Stride length in relation to total body height is also expressed as a ratio, and this ratio is derived by dividing the total body height by the stride length. This quotient is the stride length to total body height ratio.

Running Economy - Running economy is defined as the steady state oxygen consumption at standardized running speeds.

Maximal Steady State - Maximal steady state is the oxygen consumption at which the plasma lactate concentration is equal to 2.2 millimoles per liter of blood plasma.

Leg Length - Leg length was determined by measuring the distance from the greater trochanter down the lateral side of the leg to where the foot contacted the floor.

CHAPTER 2

REVIEW OF LITERATURE

Relationship Between Plasma Lactate Accumulation and Distance Running Performance

Lactic acid is the final product of anaerobic glycolysis. During this anaerobic process a six-carbon high energy glucose molecule is broken down in a series of reactions to two three-carbon lactic acid molecules. These lactic acid molecules are on a lower energy level than the original glucose molecule. The energy liberated by anaerobic glycolysis is used to resynthesize adenosine triphosphate (ATP). The anaerobic degradation of glucose is a very inefficient energy producing process since there are only two ATP molecules resynthesized per molecule of glocuse degraded. Lactic acid, the final product of anaerobic glycolysis, contains a substantial amount of energy locked in its chemical bonds. Thus, anaerobic glycolysis does not fully degrade the glucose molecule, and as a result only two ATP molecules can be regenerated per glucose molecule. To rely heavily on the anaerobic energy system causes fatigue to occur rapidly. There are two major reasons why fatigue occurs rapidly during high utilization of the anaerobic energy system. First, there is a rapid depletion of muscle glycogen, and second, a rapid increase occurs in the concentrations of lactic acid and hydrogen ions inside the muscle cells, which in turn, inhibits glycolysis (Astrand & Rodhal, 1976; Lehniger, 1982).

The rate of anaerobic glycolysis is dependent upon the concentration of ATP within the muscle cells. As the concentration of ATP decreases inside the muscle cells the rate of anaerobic glycolysis increases. When there is an adequate supply of oxygen available to the working muscles most of the energy needed to resynthesize ATP is produced within the mitochondria through the more efficient aerobic energy system. If there is an inadequate supply of oxygen in the working muscle cells the rate of anaerobic glycolysis and lactic acid production increases proportionately. Once the intensity of the exercise is raised to the point where the work load greatly exceeds the ability to supply oxygen to the working muscles the concentration of lactic acid inside the muscle cells increases exponentially. The increased acidity of the cellular environment inhibits the function of phosphorylase and phosphofructokinase. As the inhibition of phosphofructokinase and phosphorylase increases, the rate of glycolysis is drastically reduced causing a reduction in muscular work and human performance (Lamb, 1978).

Farrell, Wilmore, Coyle, Billing, and Costill (1979) studied 18 experienced male long distance runners to determine the effects of plasma lactate accumulation on long distance running performance. Each subject was tested at a total of eight different running speeds on the treadmill. The speed of the treadmill varied from 241 meters/min. to 322 meters/min. during the testing procedures. One of the treadmill speeds was set at a speed to duplicate the velocity that the distance runner used during a race situation. Multiple regression analysis was used to determine the relationships that existed between distance running performance and the following variables: aerobic capacity, treadmill velocity, running economy, muscle fiber composition, and plasma lactate accumulation. The authors found that the mean maximal oxygen uptake relating to the onset of plasma lactate accumulation was 69.9 percent of the aerobic capacity. The onset of plasma lactate accumulation was highly correlated with the race pace used by the long distance runners in this study. Running economy, maximal oxygen uptake, and muscle fiber composition were not directly related to the performance measures. It was suggested by the authors that the aerobic capacity, running economy, and muscle fiber composition were not powerful enough to directly effect long distance running performance, but when all of these variables combine simultaneously they interact to help in the control of the onset of plasma lactate accumulation. Plasma lactate accumulation was the only variable found to be directly related to long distance running performance.

Costill, Thomason, and Roberts (1973) conducted a study involving 16 male long distance runners to determine the effects of aerobic capacity, heart rate, and blood lactate accumulation on long distance running performance during maximal and submaximal treadmill running. The subjects for this study were all highly trained but there was a large variability in the distance running abilities within this group. The following correlations were found by the authors. A strong negative correlation ($r = -0.91$) was found between aerobic capacity and long distance running performance. A high positive correlation ($r = 0.94$) was found between oxygen consumption at the submaximal running speed of 268 meters/min. and distance running performance. There was also a high correlation (r = 0.98) between the percentage of maximal heart rate utilized during the submaximal runs at 268 meters/min. and the performance measures of the subjects. There was also a strong positive correlation (r = 0.91) between blood lactate accumulation and distance running performance.

Conley and Krahenbuhl (1980) designed a study to determine the effects of running economy on distance running performance. The subjects in this study were 12 highly trained distance runners. Each subject attended two testing sessions. During the first session each runner was administered a maximal oxygen uptake test. On the next day of testing each subject was run at three submaximal speeds (241, 268, and 295 meters/min.) on the treadmill to determine the oxygen consumption at these three different running speeds. Running performance was based on each of the runner's time in a national caliber 10 kilometer race. A low correlation (r = 0.12) was discovered between maximal oxygen uptake and distance running performance. The correlations between oxygen consumption at the three submaximal running speeds and distance running performance ranged from (r = 0.79) to (r = 0.83). These findings were determined to be statistically significant at the 0.01 level of confidence. The average of the R^2 values for the three submaximal runs revealed that among the highly competitive distance runners in this study 65.4 percent of the differences within the performance measures of these subjects can be directly ascribed to variations in running economy. From the results of this study the authors concluded that a large maximal oxygen uptake is a prerequisite for successful long distance running but aerobic power alone is not a reliable predictor of running performance. Running economy was shown to account for a large fraction of variation in running performance observed within the highly trained distance runners in this study.

Costill (1970) examined 42 highly trained long distance runners to determine the relationships between blood lactate accumulation and the aerobic requirement during sustained treadmill runs. Each subject was administered a maximal oxygen uptake test on the treadmill. Each subject was also required to run at six different submaximal speeds on the treadmill. Gas samples were taken at each of the submaximal speeds to determine the oxygen requirement during each of the six submaximal runs. Blood samples were also taken at each submaximal run and analyzed for blood lactate accumulation. Each runner in this study had a large aerobic capacity and was required to exceed 70 percent of his maximal oxygen uptake before blood lactate began to accumulate.

LaFontaine, Londeree, and Spath (1981) investigated the relationships between maximal steady state treadmill velocity and maximal performance times for distances ranging from 13.7 meters to 20 kilometers. Seven well trained distance runners served as subjects for this study. Maximal oxygen uptake was determined on one day, and on the second day each subject was required to run two submaximal treadmill runs to determine the maximal steady state of each runner. The speed of the treadmill during the first submaxmial run was set at a speed slightly slower than the runner's best time in a recent 16.09 kilometer run. During the second run the speed of the treadmill was adjusted to duplicate the runner's best time in a recent 8.05 kilometer race. Gas samples and blood samples were analyzed during both of the submaximal runs to determine the oxygen requirement and blood lactate accumulation during each of the submaximal runs. The authors found that maximal steady state correlated highly with race pace for distance races ranging from 440 yards to 12.4 miles. Very high correlations were found between the maximal steady state and the race pace for 2 miles ($r = 0.933$), 5 miles ($r = 0.995$), and 12.4 miles ($r = 0.984$). These results indicated that maximal steady state can be predicted from maximal performances in distance races or time trials ranging from 2 to 12.4 miles.

Relationship Between Stride Length and Distance Running Performance

Cavanagh and Williams (1982) studied the effects of stride length variation on oxygen consumption during long distance running. Ten well trained runners served as subjects in this study. Each subject was required to run on the treadmill and the runner was tested for oxygen consumption at seven different stride lengths. One of the stride lengths was the subject's freely chosen stride length, and the other six stride lengths varied by ± 6.7, ± 13.4, and ± 20 percent of the leg length from the freely chosen stride length. The speed of the treadmill was kept at a constant rate of 3.83 meters/sec. throughout the experiment. The researchers found a low correlation ($r = 0.41$) between oxygen consumption and optimal stride length. There was also a low correlation ($r = 0.27$) between oxygen consumption and optimal stride length expressed as a percentage of leg length. No relationship ($r = 0.09$) was found between leg length and optimal stride length which indicated that stride length is not consistently dependent upon leg length. Considerable shortening and lengthening of each subject's stride length resulted in only slight changes in oxygen consumption.

Nelson and Gregor (1976) found that collegiate long distance runners tended to decrease their stride length, and time of support with an increase in stride rate over a four year period. The subjects for this study were 21 competitive male long distance runners. High speed cinematography was used to film the subjects at running speeds of 16 feet/sec., 22 feet/sec., and maximum speed. The following variables were analyzed in relation to running speed: stride length, stride rate, time of support, and time of nonsupport. The results of this study indicated that all of the subjects in this study experienced some gain in performance during their collegiate careers. The authors also found that nine of the runners that completed this study tended to shorten their stride lengths and increase their stride rates with concurrent reductions in stride and support time at the same absolute running speeds. From these results it was concluded that collegiate long distance runners experience significant changes in running mechanics over a four year period.

Cavanagh, Pollock, and Landa (1977) conducted a study to determine the biomechanical differences between good and elite distance runners. The subjects in this study consisted of 14 elite and 8 good distance runners. High speed cinematography was used to film each subject while running on a treadmill at speeds that varied from 4.96 to 6.44 meters per second. The elite runners tended to take shorter strides and shorter relative strides than the good group of runners. The times of support and flight were not significantly different between the two groups. An important finding in this study was that the elite group used stride lengths that were closely related (r = 0.67) to their leg lengths. The good group showed a low correlation (r = 0.10) between stride length and trochanter height. These findings revealed that the elite group of runners used shorter strides that closely matched their leg lengths; while the good runners used longer stride lengths regardless of their leg lengths.

Roy (1982) devised a study to determine the biomechanical variables that are most important in long distance running. The subjects for this study were 14 male and 6 female long distance runners. Testing procedures involved high speed cinematography. Each subject was filmed while running on a 200 meter track at speeds that ranged from 12.2 to 19.3 kilometers/hour. The data were analyzed in relation to running speed. Significant correlations were found between running velocity and the following temporal variables: time of support (r = -0.83), stride length (r = 0.88), relative stride length (r = 0.88), and stride length/height (r = 0.89). Multiple regression analysis revealed that 85 percent of all the variation in running velocity could be accounted for by time of support (69 percent), stride length (14 percent), and the final two percent of the variation was attributed to stride rate. Thus as the speed of running increases time of support, stride length, and stride rate are adjusted to compensate for the change in velocity.

Knuttgen (1961) found that minor deviations from the optimal stride length did little to effect energy demand, but drastic increases in energy expenditure were noticed with greater deviations in stride length. Two well trained distance runners were chosen as subjects for this study. Each subject was tested at 11 different speeds on the treadmill. The running speeds varied from 9 to 16.5 kilometers per hour. Each subject ran at every speed using a freely chosen stride length and a determined stride length. The determined stride length was kept constant at 77 centimeters throughout the experiment. The author found that at speeds of 9.66 kilometers/hour or slower there was no difference in energy expenditure between the freely chosen stride length and the optimal stride length for each subject. At speeds above 9.66 kilometers/hour though, there was a drastic increase in the energy requirements of each subject while running with the determined stride lengths. As the speed of running increased the subject's stride length deviated further from the optimal stride length and energy expenditure increased linearly as a result.

Elliot and Blanksby (1979) designed a study to establish a technique for determining optimal stride lengths for male and female distance runners. The subjects in this study were 10 male and 10 female well trained recreational runners. Each subject was filmed at 100 frames per second while running on a treadmill at speeds ranging from 2.5 to 5.5 meters/second. The films were analyzed to determine the stride length and stride rate of each runner at the four standard running speeds. The authors found that there was a linear change in stride length and stride rate increased as the speed of running increased. Significant correlations were found for the females between stride length and leg length for the following runinng speeds: 2.5 meters/sec. ($r = 0.69$), 3.5 meters/sec. ($r = 0.67$), 4.5 meters/sec. ($r = 0.70$), and 5.5 meters/sec. ($r = 0.74$). Significant correlations were found for the males between stride length and trochanter height at 3.5 meters/sec. ($r = 0.69$), 4.5 meters/sec. ($r = 0.68$), and 5.5 meters/sec. ($r = 0.70$). The authors also found significant correlations between total body height and stride length at all speeds in the female group. These findings indicate that height and leg length may be important factors in determining an optimal stride length for the long distance runner.

Nelson and Osterhoudt (1971) conducted a study to determine the effects of three different grades and running speeds on the mechanics of long distance runners. Sixteen experienced male long distance runners served as subjects in this study. High speed cinematography was used to film each subject at running speeds of 11, 16, and 21 feet per second. Stride length, stride rate, period of support, and period of nonsupport were analyzed in relation to running speed. The analysis indicated that all running speeds caused significant variations in stride length. As the speed of running increased, stride length increased. The time of support decreased as the speed of running increased. Time of nonsupport also decreased as running speed increased. Lastly, stride rate increased as running velocity increased.

Nelson, Brooks, and Pike (1977) compared the biomechanical characteristics of male and female long distance runners. The subjects in this study were 21 elite female long distance runners and 14 elite male long distance runners. Each subject was filmed at four different running speeds ranging from the marathon pace to maximum speed. The female runners demonstrated significantly shorter stride lengths and higher stride rates compared to the males. Although, the females used shorter absolute strides the females were shown to have significantly longer relative stride lengths than the males. The results also revealed that the females had a shorter time of support, a greater time of nonsupport, and lower ratios of time of support/stride time. Thus the females in this study demonstrated a shorter contact time and a conversely longer flight time. The females were in flight four percent longer than the males and covered four percent less absolute distance than the males. However, these differences could not be completely explained by the anthropometric differences of the male and female distance runners in this study. This finding indicates that the female distance runners are biomechanically less efficient than their male counterparts.

Overground Running Versus
Treadmill Running

Nelson, Dillman, Lagase, and Bickett (1972) designed a study to determine the biomechanical differences between overground and treadmill running. The subjects in this study were 16 highly trained distance runners. Each subject was required to run at three different speeds (3.35, 4.88, 6.40 meters/sec.) and on three different slopes (horizontal, 10 percent uphill, and 10 percent downhill). This protocol was used for both overground and treadmill running. The authors found treadmill running to be characterized by the following movement patterns: longer periods of support, lower vertical velocities of the body, and less variability in the horizontal and vertical velocities of the body. These findings lead the authors to conclude that there are significant differences between the biomechanical patterns of treadmill and overground running.

Dal Monte, Fucci, and Mononi (1973) investigated the differences in the biomechanical and physiological characteristics of overground and treadmill running. Each runner in this study ran at three different submaximal velocities (4.2, 5.0, and 5.6 meters/sec.) during the overground and treadmill tests. The authors of this study found only slight differences in vertical displacement of the body, extension phase and stride length. The findings also revealed that differences in movement patterns became less as the speed of running increased. Very small differences were reported in the physiological responses during treadmill and overground running. The authors concluded that there were no significant differences in the mechanical patterns or the energy requirements during treadmill running. Therefore, the treadmill could be used as a simulator for middle distance running.

Schenau (1980) challenged the traditional methods of comparing treadmill running to overground running. The author points out that the majority of research dealing with running mechanics on the treadmill have used a fixed coordinate system. To obtain accurate measures of mechanical movement of the treadmill a moving coordinate system must be used. Most importantly the author emphasizes there is no difference between overground and treadmill running when the mechanical variables are analyzed in relation to the surface on which the subject is moving. It was concluded that the only significant difference between treadmill running and overground running was air resistance. During treadmill running the air resistance is practically zero, but during overground running air resistance can account for 13 percent of the runners total energy requirement.

CHAPTER 3

PROCEDURES

Overview

The purpose of this study was to determine the effects of stride length on the plasma lactate accumulation among highly trained distance runners. Each subject was required to visit the Human Performance Laboratory on two separate occasions. During the first visit each subject was administered a metabolic stress test using the Bruce Graded Exercise Protocol (See Appendix A for Bruce Grade Exercise Protocol). On the second visit each runner was required to complete two submaximal runs on the treadmill. The intensities of the submaximal runs were 70 and 85 percent of the runner's aerobic capacity. Blood samples were drawn from the anticubetal artery at rest following a 5 minute rest period, after the submaximal run at 70 percent of each subject's aerobic capacity, and after the submaximal run at 85 percent of the runner's maximal oxygen uptake. A 5 minute rest period was administered between the drawing of blood and the completion of each submaximal run. Stride length and relative stride length measures were also calculated during each of the submaximal runs after a steady state of exercise had been reached.

The subjects that particpated in the present study were 10 highly trained male long distance runners at Appalachian State University. Seven of the runners were cross country and track runners at ASU, and the other three runners were competitive distance runners at ASU but were not members of the track or cross country teams. A highly competitive group was chosen for this study to control for differences in the biochemical and physiological levels of conditioning among the subjects. The purpose of this selection process was to control the levels of conditioning among the athletes, so that the relationships between stride length and plasma lactate accumulation could be manifested.

The primary purpose of the first testing session was to determine each runner's aerobic capacity. Upon arrival at the Human Performance Laboratory each subject's height and weight were determined using a balance beam type medical scale. Each subject's height and weight measurements included the shoes and clothing that the runner was wearing. Each subject was then equipped with the breathing apparatus and supporting headgear, and connected to a Beckman MMI Metabolic Cart with low resistance tubing. Once the headgear and breathing apparatus were fitted comfortably the subject was administered a maximal treadmill run using the Bruce Graded Exercise Protocol. Gas samples were analyzed every 30 seconds for CO_2 and O_2 concentrations and oxygen consumption was recorded at the end of each 30 second period. The highest oxygen consumption achieved toward the end of the treadmill test was recorded as the subject's aerobic capacity. Each subject read and signed a consent to procedure form before any of the above tests were administered (See Appendix B).

One week following the metabolic stress test the subjects returned to the Human Performance Laboratory. Each subject's height and weight were again recorded. Running shoes and clothes were included in all height and weight measurements. A Gulick Tape Measure was used to measure each runner's leg length. Measurements were taken from the greater trochanter to the lateral side of the foot. The heights of the running shoes were included in all of the leg length measurements.

After the subject's height, weight, and leg length were measured the subject was again equipped with the breathing apparatus, supporting headgear and connected to the metabolic cart. Gas samples were analyzed every 30 seconds and the treadmill speed was gradually increased until the runner's oxygen consumption was equal to 70 percent of his aerobic capacity. After the subject had stabilized at the 70 percent workload for 1.5 minutes the headgear and breathing apparatus were removed and the subject was then required to run for an additional 5 minutes. Heart rate was monitored throughout the run to assure that the workload remained constant after the headgear was removed. The headgear and breathing appartus were removed so that each runner could run freely without any interference from the metabolic equipment. During the last minute of the 5 minute run without the metabolic equipment, the runner's stride length and running speed were automatically recorded using a microcomputer. Once the stride length measures were completed the subject was removed from the treadmill and asked to remain seated for 5 minutes. At the end of this 5 minute period another blood sample was drawn.

After the completion of the first submaximal run the subject was again equipped with the breathing devices and connected to the metabolic cart. The speed of the treadmill was slowly increased until the subject was utilizing 85 percent of his aerobic capacity. After 3 consistent metabolic readings were obtained the breathing apparatus was removed and the runner was again required to run for an additional 5 minutes. At the end of the 5 minute run stride length and treadmill speed were again determined. Once stride length and treadmill speed were determined the runner was removed from the treadmill and asked to remain seated for 5 minutes. At the end of the 5 minute rest period a third blood sample was drawn. All three blood samples were then spun down and analyzed for plasma lactate concentration using a Yellow Springs Instruments Lactate Analyzer. All of the data were recorded on subject information forms (See Appendix C).

Equipment

Beckman MMI Metabolic Cart - The metabolic cart was used to analyze expired air for oxygen and carbon dioxide concentrations.

Balance Beam Type Medical Scale - The medical scale was used to measure height and weight.

Yellow Springs Instruments, Model 23L Lactate Analyzer - The lactate analyzer was used to measure the concentrations of lactate present in the blood plasma.

Vacutainers - Vacutainers containing potassium oxalate and sodium flouride were used to draw and hold blood samples.

Centrifuge - A centrifuge was used to separate the blood plasma from the hematocrit.

Respironics Inc., Exersentry Heart Rate Monitor - An Exersentry Heart Rate Monitor was used to monitor heart rate throughout the maximal and submaximal treadmill runs.

Commodore Business Machines Model 4032 Microcomputer - The computer was used to calculate treadmill speed, stride length, and stride length in relation to leg length and total body height.

Treadwork Computer Program - The computer program was designed by Mark T. Harris to input the subject's name, leg length, total body height, time between heel strikes, and time per belt revolution. Once this information was gathered, the program was then designed to output stride length, stride length in relation to leg length, stride length in relation to total body height and treadmill speed. All values were computed to the nearest 0.01 of a second.

Analog to Digital Converter - The A to D Converter was constructed by Dr. Robert Nicklin of the A.S.U. Physics Department and was used to convert analog data to digital information.

Switchmat - A switchmat was embedded in the treadmill platform and was used in conjunction with the computer equipment to determine time between footstrikes and ultimately stride length.

Microswitch - A mechanical microswitch was placed on the platform surrounding the treadmill belt and a triggering device was attached to the treadmill belt. These devices were used along with the computer equipment to determine belt speed during the testing procedure.

Three Way Toggle Switch - The three way switch was used to connect the switchmat and microswitch to the A to D converter.

Coaxial Wire - The coaxial wire was used to connect the switchmat and the microswitch to the three way switch.

Gulick Tape - The gulick tape was used to measure trochanter height.

Procedure for Determining

Maximal Oxygen Uptake

Maximal oxygen uptake was measured directly using a Beckman Metabolic Cart. Each subject was run to exhaustion using the Bruce Graded Exercise Test. During the maximal treadmill run the subjects were equipped with a mouthpiece, threeway valve, nose clip, supporting headgear, and attached to the metabolic cart through low resistance tubing. Oxygen consumption was recorded every 30 seconds, and the highest oxygen consumption recorded toward the end of the run was the runner's maximal oxygen uptake.

Procedure for Collecting

Blood Samples

Blood samples were drawn from the anticubital vein into vacutainers containing potassium oxalate and sodium fluoride just prior to, and 5 minutes following, each submaximal test. A laboratory technician was present to draw all blood samples.

Procedure for Determining

Plasma Lactate Concentration

The blood samples were spun down in a centrifuge to separate the plasma from the hematocrit. Twenty-five microliters of blood plasma were then analyzed for lactate concentration using a YSI 23L Lactate Analyzer.

Procedure for Determining

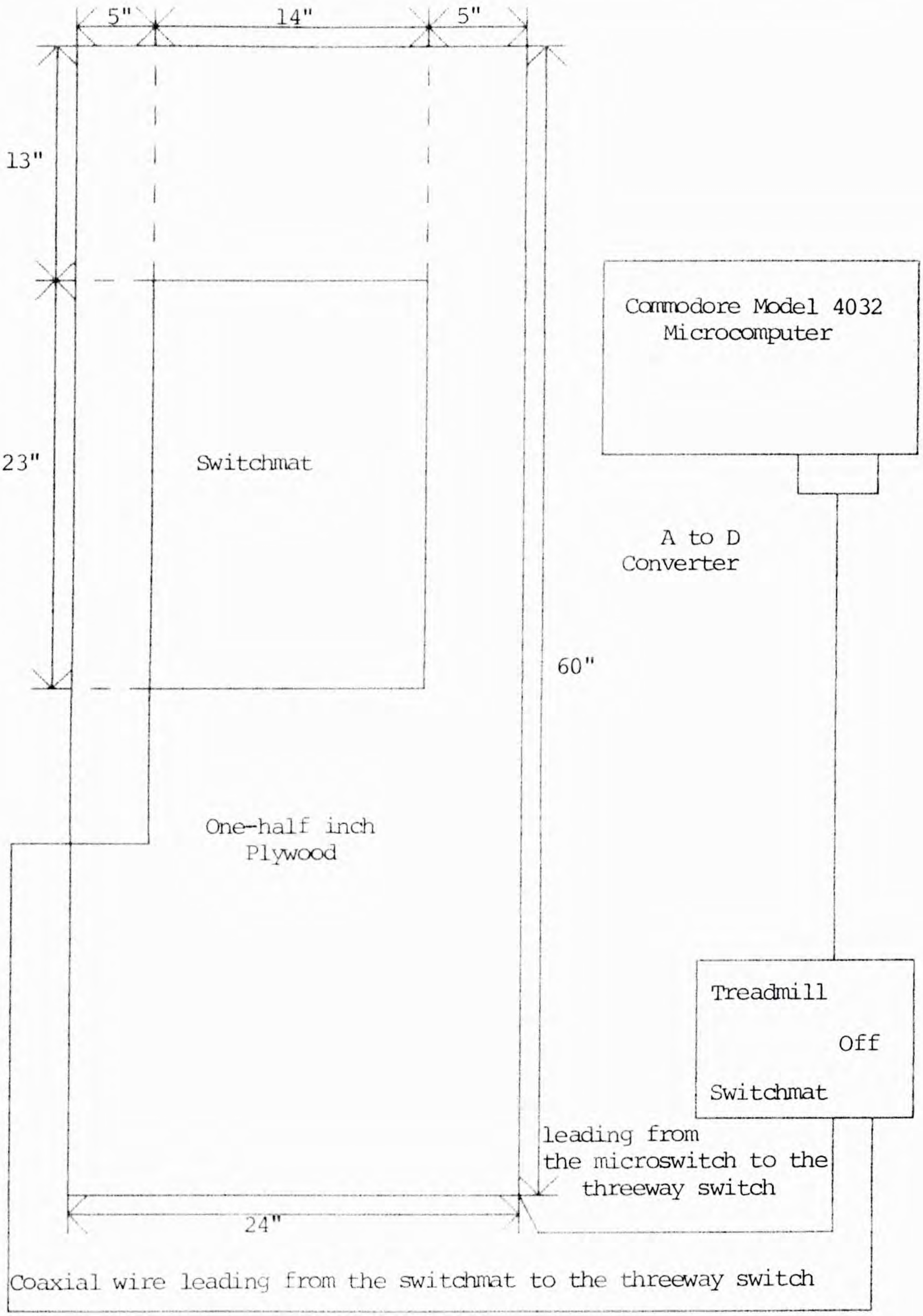
Submaximal Workloads

Two relative submaximal treadmill runs were used in this study. The intensities of the two runs were 70 and 85 percent of the aerobic capacity. Each subject was connected to the metabolic cart and the speed of the treadmill was slowly increased until the subject was utilizing 70 or 85 percent of the respective maximal oxygen uptake. Once the subject reached the desired intensity oxygen consumption was monitored closely for 1.5 minutes to assure that the workload remained constant. After the oxygen uptake stabilized the metabolic equipment was removed. Heart rate was monitored with an Exersentry Heart Rate Monitor to assure that the workload remained constant throughout the testing.

Procedure for Determining
Time Between Heel Strikes

The platform under the treadmill belt was removed and a specially constructed platform was used as a replacement. The specially constructed platform was constructed of plywood and was covered with teflon coated aluminum. Toward the front of the platform a 14" x 23" section was cut out of the plywood and a switchmat of the same dimensions was inserted into the space. Coaxial wire led from the switchmat to a threeway toggle switch. The toggle switch, in turn, was attached to an A to D converter, and the A to D converter was connected to the user port of a Commodore Model 4032 Microcomputer. A specially prepared computer program was then used to determine the time between heel strikes to the nearest 0.01 of a second (See Figure 1 for a diagram of the equipment used to determine stride length).

Figure 1. Diagram of the Equipment Used to Determine Stride Length



Procedure for Determining

Treadmill Belt Speed

A microswitch was securely fastened to the running board that surrounds the treadmill belt. The mechanical microswitch was attached to the bottom of the running board and was placed near the belt surface. A small piece of copper metal was glued to the treadmill belt and acted as a trigger to close the microswitch after each belt revolution. Coaxial wire led from the microswitch to the threeway toggle switch. The toggle switch was attached to an A to D converter, which in turn, was connected to the user port of the Commodore Model 4032 Microcomputer through the computer's user port. The specially prepared computer program was then used to determine the time per belt revolution. Treadmill speed was then determined by dividing the treadmill belt length by the time between switch closures. Time between switch closures is the same as time per belt revolution.

Procedure for Determining

Stride Length

During the last minute of each submaximal run stride length and treadmill speed were recorded. The microswitch, switchmat and microcomputer were all used to make these measurements. The Treadwork program was loaded into the computer. The program was designed to input the runner's name, leg length, and total body height. After this information was entered into the computer, the user could determine treadmill speed by hitting the return key and then hitting any key after an ample number of switch closures. Once the belt speed was determined the toggle switch was moved from the treadmill position to the switchmat. Time between heel strikes was recorded for a total of 50 strides. The computer then calculated stride length by multiplying the time between heel strikes by the treadmill belt speed. The computer also calculated stride length in relation to trochanter height and total body height.

Interpretation of Data

Pearson Product Correlations were used to analyze the data gathered in this study. Correlations were used to determine the relationships between plasma lactate accumulation and the following variables: stride length, stride length in relation to leg length, and stride length in relation to total body height. Correlations were also used to determine the relationships between stride length and the following two anatomical variables: leg length, and total body height. The following relationships were also analyzed using Pearson Product Correlations: (1) stride length in relation to treadmill speed, (2) maximal oxygen uptake in relation to running speed, and (3) plasma lactate accumulation in relation to running speed.

CHAPTER 4

PRESENTATION AND ANALYSIS OF DATA

Summary

The purpose of the present study was to determine if there were significant correlations between relative stride length measures and plasma lactate accumulation at two relative and submaximal running intensities. Ten competitive male long distance runners volunteered to participate in this study. Each subject was required to report to the Human Performance Laboratory on two separate days to complete the testing procedures. During the first session each subject was required to complete a metabolic stress test to determine the runner's aerobic capacity. On the second testing session the subject was required to run at two different submaximal speeds on the treadmill. Plasma lactate accumulation and stride length were determined at each of these submaximal running speeds.

Prior to the first testing session each subject was instructed to wear comfortable running attire and to avoid any food intake 3 hours before their testing session. Upon arrival at the Human Performance Laboratory on the first day each subject's body weight and height were determined using a balance beam type medical scale. After body weight and height were determined the subject was equipped with a mouthpiece and the breathing apparatus and then attached to a Beckman MMI Metabolic Cart through low resistance tubing. The subject was also equipped with an Exersentry Heart Rate Monitor. When properly fitted with the metabolic and heart rate monitoring equipment each subject was requested to run to exhaustion on the treadmill using the Bruce Graded Exercise Protocol. The highest oxygen consumption achieved toward the end of the maximal treadmill run was considered the individual's aerobic capacity. The first testing session was completed when aerobic capacity was determined.

The objective of the second testing session was to determine each runner's stride length and plasma lactate concentration at two relative and submaximal running intensities. Body weight and height were again measured as soon as each subject arrived at the Human Performance Laboratory on the second day. Leg length was then determined by measuring the distance from the greater trochanter down to the lateral side of the foot. Running shoes and clothes were included in all weight and height measurements. Following the height and weight measurements the subject was asked to remain seated for 5 minutes, after which time a resting blood sample was drawn. The subject was then required to complete two submaximal runs on the treadmill. The intensities of these runs were 70 and 85 percent of the individual's aerobic capacity. Stride length measurements were taken toward the end of each submaximal run and blood samples were drawn 5 minutes following each of the submaximal runs.

Once the three blood samples were drawn and spun down in a centrifuge, the plasma lactate concentration was determined using a YSI Lactate Analyzer. After the plasma lactate analysis was completed multiple correlations were done to determine the relationships that existed between plasma lactate accumulation and the following variables: stride length, stride length in relation to leg length, and stride length in relation to total body height while running at 70 and 85 percent of the aerobic capacity.

Analysis of Data at 70 Percent of the Aerobic Capacity

Table 1 reveals that there were significant correlations between plasma lactate accumulation (see Appendix D for raw data concerning plasma lactate concentrations) while running at 70 percent of the aerobic capacity and the following variables: running speed (r = 0.630) and the leg length to stride length ratio (r = -0.749) at the same relative running intensity (see Appendices E and F for raw data of stride lengths and relative stride lengths). These findings indicate that the runners who accumulated the highest concentrations of plasma lactate while running at 70 percent of the aerobic capacity ran at slower speeds and used longer strides when stride length was expressed as a percentage of leg length. A significant correlation was also shown between stride length and leg length at a running intensity of 70 percent of the aerobic capacity (r = 0.648) indicating that stride length was closely related to leg length (see Appendix G for raw data concerning the physical characteristics of the subjects) at the running intensity of 70 percent of the aerobic capacity.

Two relatively high but nonsignificant correlations are also shown in Table 1. The coefficient of correlation between the plasma lactate accumulation while running at 70 percent of the aerobic capacity and the height to stride length ratio at this same intensity (r = -0.569) was approaching the significance level but was nonsignficant at the

Table 1

Intercorrelations Between Variables at 70 Percent of the Aerobic Capacity

Variable	2	3	4	5	6	7	8
1. Running Speed	-0.070	-0.630+	-0.037	0.349	0.229	0.378	0.249
2. Aerobic Capacity	—	0.333	0.212	-0.479	-0.172	-0.148	-0.013
3. Lactate Accumulation		—	0.321	-0.749+	0.569	-0.352	-0.302
4. Stride Length			—	-0.704+	-0.739+	0.648+	0.576
5. Leg Length/Stride Length				—	0.817*	0.078	0.023
6. Height/Stride Length					—	-0.124	0.114
7. Leg Length						—	0.867*
8. Height							—

* Significant at the 0.01 level of confidence

+ Significant at the 0.05 level of confidence

0.05 level of confidence. This finding indicates that the runners who accumulated the higher concentrations of plasma lactate while running at 70 percent of the aerobic capacity also used the longest strides when stride length was expressed as a percentage of total body height. A relatively high but nonsignificant correlation ($r = 0.576$) was also found between stride length and total body height at the running intensity of 70 percent of the aerobic capacity. This correlation between stride length and total body height indicates that height plays a definite role in determining stride length among highly trained distance runners, but height alone is not a powerful enough variable to be significantly correlated with stride length.

Several low correlations are also shown in Table 1. A very low correlation was reported between running speed and stride length while running at 70 percent of the aerobic capacity ($r = -0.037$) indicating that running speed is not a major factor involved in determining the stride lengths of highly trained distance runners. A low correlation ($r = 0.321$) was also reported between stride length and plasma lactate accumulation while running at 70 percent of the aerobic capacity. This low correlation was expected since stride length alone does not take into account leg length or total body height. The correlation shown in Table 1 between maximal oxygen uptake and running speed at 70 percent of the aerobic capacity ($r = -0.070$) was also very low, which indicates that aerobic capacity is not a good predictor of submaximal running performance.

Analysis of Data at 85 Percent of the Aerobic Capacity

Table 2 indicates that there is a significant correlation between plasma lactate accumulation while running at 85 percent of the aerobic capacity and the height to stride length ratio ($r = -0.685$) at the same relative running intensity. This finding suggests that the runners that accumulated the highest concentrations of plasma lactate at the running intensity of 85 percent of the aerobic capacity also used the longest strides when stride length was expressed as a percentage of total body height.

Three relatively high but nonsignificant correlations are also shown in Table 2. The correlation between plasma lactate accumulation while running at 85 percent of the aerobic capacity and the leg length to stride length ratio ($r = -0.577$) was approaching the significance level, but the correlation was not powerful enough to be statistically significant. Two fairly high but not significant correlations are also shown between stride length at the running intensity of 85 percent of the aerobic capacity and the following variables: leg length ($r = 0.528$) and total body height ($r = 0.562$).

Several low correlations are also shown in Table 2. A low correlation was found between running speed and stride length at 85 percent of the aerobic capacity ($r = -0.247$) indicating that running speed is not a major factor involved in determining the stride lengths of highly trained distance runners at this submaximal running intensity. The correlation between running speed at 85 percent of the aerobic capacity and maximal oxygen uptake ($r = -0.438$) also was low. This finding indicates that maximal oxygen uptake is not a good

Table 2

Intercorrelations Between Variables at 85 Percent of the Aerobic Capacity

Variable	2	3	4	5	6	7	8
1. Running Speed	-0.119	-0.438	-0.247	0.033	0.148	0.537	0.536
2. Aerobic Capacity	—	0.172	0.186	-0.308	-0.256	-0.148	-0.013
3. Lactate Accumulation		—	0.245	-0.577	-0.685+	-0.417	-0.515
4. Stride Length			—	-0.814*	-0.755*	0.528	0.562
5. Leg Length/Stride Length				—	0.885*	0.054	0.087
6. Height/Stride Length					—	-0.028	0.056
7. Leg Length						—	0.867*
8. Height							—

* Significant at the 0.01 level of confidence

+ Significant at the 0.05 level of confidence

predictor of submaximal running performance. Another low correlation was reported between plasma lactate accumulation at 85 percent of the aerobic capacity and running speed at the same intensity (r = -0.438). This finding indicates that running speed is not directly attributed to plasma lactate accumulation at this submaximal running intensity. The correlation of stride length and plasma lactate accumulation while running at 85 percent of the aerobic capacity was also low (r = 0.245). This correlation was expected since stride length does not take into account leg length or total body height.

Intercorrelations at 70 Percent and 85 Percent of the Aerobic Capacity

Table 3 reveals several significant correlations between variables while running at 70 and 85 percent of the aerobic capacity. A very high correlation is shown between plasma lactate concentrations at 70 and 85 percent of the aerobic capacity (r = 0.869); indicating that the runners who accumulated the highest concentrations of plasma lactate while running at 70 percent of the aerobic capacity also accumulated the highest concentration of plasma lactate at the running intensity of 85 percent of the aerobic capacity. High correlations are also shown between plasma lactate at the running speed of 70 percent of the aerobic capacity and the following variables: the leg length to stride length ratio (r = -0.831) and the height to stride length ratio (r = -0.832) at the running intensity of 85 percent of the aerobic capacity. These significant correlations indicate that the runners who accumulated the highest concentrations of plasma lactate at 70 percent of the aerobic capacity also demonstrated the longest relative stride lengths while running at 85 percent of the aerobic capacity. An

Table 3

<u>Intercorrelations Between Variables at 70 and 85 Percent of the Aerobic Capacity</u>

Variable	2	3	4	5	6	7	8	9
1. Resting Plasma Lactate	0.463	0.107	0.223	0.487	-0.313	-0.584	0.121	-0.536
2. Lactate Accumulation 70%	—	0.869*	0.321	0.483	-0.749+	-0.831*	-0.569	-0.832*
3. Lactate Accumulation 85%		—	0.149	0.245	-0.557	-0.577	-0.577	-0.685+
4. Stride Length 70%			—	0.926*	-0.704+	-0.632+	-0.739+	-0.685+
5. Stride Length 85%				—	-0.704+	-0.814*	-0.651+	-0.775*
6. Leg Length/Stride Length 70%					—	0.893	0.817*	0.861*
7. Leg Length/Stride Length 85%						—	0.644+	0.885*
8. Height/Stride Length 70%							—	0.859*
9. Height/Stride Length 85%								—

* Significant at the 0.01 level of confidence

+ Significant at the 0.05 level of confidence

extremely high correlation is also reported between stride length at the running intensity of 70 percent of the aerobic capacity and stride length while running at 85 percent of the aerobic capacity (r = 0.926), which indicates that the runners who utilized the longest strides while running at 70 percent of the aerobic capacity also used the longest strides during the run at 85 percent of the aerobic capacity.

The nonsignificant correlations between resting plasma lactate concentrations and plasma lactate accumulation while running at 70 and 85 percent of the aerobic capacity (r = 0.463 and 0.107 respectively) indicate that resting plasma lactate concentrations do not play a major role in determining the exercise lactate concentrations.

CHAPTER 5

SUMMARY, FINDINGS, DISCUSSION, CONCLUSIONS,

AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the relationship between plasma lactate accumulation and relative stride length measures at two submaximal running intensities. The subjects for this study were 10 competitive male long distance runners from Appalachian State University in Boone, North Carolina. Each subject was required to make two visits to the Human Performance Laboratory. On the first visit the subject was asked to run to exhaustion on the treadmill using the Bruce Graded Exercise Protocol. Gas samples were analyzed throughout this treadmill run and maximum aerobic capacity was determined using a Beckman MMI Metabolic Cart.

During the second testing session the subject was required to complete two submaximal treadmill runs. The intensity of the first and second run was 70 and 85 percent of the subject's aerobic capacity respectively. During each of these submaximal runs the subject was equipped with metabolic and heart rate monitoring devices. After the subjects achieved the desired running intensity the breathing apparatus and headgear were removed. Once the breathing apparatus was removed the subject's heart rate was monitored closely to insure that the workload remained constant. The subject was required to run for an additional 5 minutes after the removal of the metabolic equipment to insure that a steady state had been reached before any stride length or plasma lactate samples were taken. Stride length measures were taken during the last 20 seconds of the submaximal run. Blood samples were drawn using the following protocol: prior to initial testing following a 5 minutes rest period, 5 minutes after the submaximal run at 70 percent of the aerobic capacity, and 5 minutes after the submaximal run at 85 percent of the subject's aerobic capacity. After all the data were collected multiple correlations were performed to determine the relationships between the relative stride length measures and plasma lactate accumulation.

Findings

The findings of this study for running intensities of 70 and 85 percent of the aerobic capacity are as follows:

1. No significant correlations were found between plasma lactate accumulation at the running intensity of 70 percent of the aerobic capacity and the following variables: maximal oxygen uptake, running speed at 85 percent of the aerobic capacity, resting plasma lactate concentration, stride length while running at 70 and 85 percent of the aerobic capacity, and the height to stride length ratio at the running intensity of 70 percent of the aerobic capacity.
2. Significant correlations were reported between plasma lactate accumulation at 70 percent of the aerobic capacity and the following variables: running speed at 70 percent of the aerobic capacity, the leg length to stride length ratio at a

running intensity of 70 percent of the aerobic capacity, and the leg length to stride length ratio and the height to stride length ratio at the running intensity of 85 percent of the aerobic capacity.

3. No significant correlations were found when plasma lactate accumulation at a running intensity of 85 percent of the aerobic capacity was correlated with each of the following variables: maximal oxygen uptake, running speed at 85 percent of the aerobic capacity, stride length, and the leg length to stride length ratio at a running intensity of 85 percent of the aerobic capacity.

4. Significant correlations were discovered when plasma lactate accumulation at the running intensity of 85 percent of the aerobic capacity was correlated with each of the following variables: plasma lactate accumulation while running at 70 percent of the aerobic capacity, and the height to stride length ratio at the running intensity of 85 percent of the aerobic capacity.

5. No significant correlations were reported between stride length at a running speed of 70 percent of the aerobic capacity and the following variables: running speed at 70 percent of the aerobic capacity, resting plasma lactate concentration, plasma lactate accumulation while running at 70 percent of the aerobic capacity and total body height.

6. A significant correlation was reported between stride length at the running intensity of 70 percent of the aerobic capacity and leg length.

7. No significant correlations were found between stride length while running at 85 percent of the aerobic capacity and the following variables: running speed at 85 percent of the aerobic capacity, resting plasma lactate concentration, plasma lactate accumulation at the running intensity of 70 percent of aerobic capacity, plasma lactate accumulation during the run at 85 percent of the aerobic capacity, leg length and total body height.

8. No significant correlations were found when running speed at 70 percent of the aerobic capacity was correlated with each of the following variables: stride length while running at 70 percent of the aerobic capacity, the leg length to stride length ratio at the running intensity of 70 percent of the aerobic capacity, and the height to stride length ratios while running at 70 and 85 percent of the aerobic capacity.

9. There were also no significant correlations found between running speed and the following variables: maximal oxygen uptake, stride length at the running intensity of 85 percent of the aerobic capacity, and the height to stride length and leg to stride length ratios while running at 85 percent of the aerobic capacity.

Discussion

Plasma Lactate Accumulation in Relation to Stride Length Measures

In the present study no significant correlations were found between stride length and plasma lactate accumulation at the running intensities of 70 and 85 percent of the aerobic capacity. However, when stride length was expressed in relation to leg length and total body height, and then correlated with plasma lactate accumulation several significant correlations were discovered. Significant correlations were found between plasma lactate accumulation at the running intensity of 70 percent of the aerobic capacity ($r = -0.749$), and the leg length to stride length ratio while running at 85 percent of the aerobic capacity ($r = 0.832$). The above correlations were statistically significant at the 0.01 level of confidence. The correlation between plasma lactate accumulation at the running intensity of 85 percent of the aerobic capacity and the height to stride length ratio at the same relative intensity ($r = -0.685$) was statistically significant at the 0.05 level of confidence. A relatively high but nonsignificant correlation ($r = -0.569$) was reported between the plasma lactate accumulation at a workload of 70 percent of the aerobic capacity and the height to stride length ratio at this same intensity. The correlation reported between plasma lactate accumulation while running at 85 percent of the aerobic capacity and the leg length to stride length ratio at the same relative intensity ($r = -0.577$) was approaching the significance level, but was nonsignificant at the 0.05 level of confidence.

Four significant correlations were found in the present study between the plasma lactate accumulation and stride length expressed as a percentage of leg length and total body height at two relative and submaximal running intensities. Farrell, Wilmore, Coyle, Billing, and Costill (1979) found that the average intensity at which the onset of plasma lactate accumulation occurred was 69.9 percent of the aerobic capacity in highly trained distance runners. The authors also reported that the running intensity at which the accumulation of plasma lactate began to occur was highly correlated with the race pace used by the distance runners during competition. The more talented runners were capable of running at higher intensities before plasma lactate began to accumulate, whereas, their less skilled counterparts began to accumulate plasma lactate at lower running intensities.

The findings of the present study revealed that there were significant correlations between plasma lactate accumulation and stride length at two submaximal and relative running intensities. Based on the findings by Farrell et al. (1979) it was deduced that the runners in the present study that accumulated the highest concentrations of plasma lactate at each of the relative running intensities were also the less skilled performers. Conversely, the better runners accumulated less plasma lactate at each of the relative running intensities. Based on the findings of the present study and the findings of Farrell et al. (1979) it was concluded that the less skilled distance runners in the present study accumulated higher concentrations of plasma lactate and used longer relative stride lengths at each of the submaximal running speeds. The more talented runners accumulated less plasma lactate and also used shorter stride lengths at the same submaximal and relative running intensities.

Two previous studies (Cavanagh et al., 1977; Nelson et al., 1976) reported that the highly skilled or elite distance runners tended to use shorter relative stride lengths than their less skilled counterparts at the same absolute running intensities. The authors of these studies attributed the variations observed in the stride habits between the elite and good distance runners to differences in mechanical efficiency. The elite runners used shorter stride lengths at the same absolute running speeds, and the authors concluded that it may be mechanically more efficient to understride than to grossly overstride.

The author of the present study wishes to propose another explanation for the differences found in the stride habits of the highly skilled and less talented distance runners at the same relative or absolute running intensities. In the present study significant correlations were reported between plasma lactate accumulation and stride length expressed as a percentage of leg length and total body height at two submaximal running speeds. The runners in the present study that accumulated the highest concentrations of plasma lactate at each of the submaximal running speeds also used the longest relative stride lengths, thus it seems that the stride length used by a distance runner is to a large extent determined by the runner's skill level and the rate at which the runner is accumulating lactate at a given intensity. The rate at which latate is accumulated at a given running intensity is also highly correlated with the runner's skill level.

The interrelationships discussed above between plasma lactate accumulation and stride length parameters are best explained as follows. The less skilled runners accumulate higher concentrations of plasma lactate at the same relative or absolute running intensities. It is possible to deduce then that the less skilled runners become more fatigued at the same running intensities than their more highly skilled counterparts. It is the conclusion of this author that the less skilled runner experiences a higher level of exertion during a given submaximal run and that this higher level of exertion is responsible for the differences found in the stride habits of the highly skilled and less skilled distance runners at the same relative and absolute running intensities. The less skilled runners perceived the running intensities to be more difficult and as a result increased their stride lengths to meet the demands of the workload. The more highly skilled runners considered the running intensities to be easier than the less skilled runners did, and as a result the elite runners are able to use shorter strides. Thus, it is the fatigue experienced by the runner that is to a large extent responsible for the stride length used by the athlete, and not necessarily the running speed of the performer.

Stride Length in Relation to Treadmill Speed

In the present study very low correlations were reported between stride length parameters and treadmill speed. At a running intensity of 70 percent of the aerobic capacity low correlations were reported between treadmill speed and the following stride length parameters: stride length ($r = -0.037$), stride length in relation to leg length ($r = 0.349$), and stride length in relation to total body height (r = 0.229). Low correlations were also found when running speed at 85 percent of the aerobic capacity was correlated with the following variables: stride length (r = 0.247), stride length in relation to leg length (r = 0.033), and stride length expressed as a percentage of total body height (r = 0.148). These findings indicate that there are no significant correlations between treadmill speed and the stride length parameters at both relative and submaximal running intensities.

The low correlations reported between treadmill speed and the stride length parameters analyzed in the present study indicate that running speed is not a major factor involved in determining the stride length of the highly trained distance runner. These findings further support the conclusion that the rate at which lactate is being accumulated and the athlete's level of perceived exertion are the major factors involved in determining the distance runner's stride length.

The low correlations reported between treadmill speed and the stride length parameters also indicates that absolute and even relative running speeds may not be reliable methods of comparing the mechanics of elite and less skilled distance runners. Since running speed alone does not determine a runner's stride length, it would not seem sufficient to evaluate each runner's stride habits at the same predetermined running speeds. In order to do an effective and reliable comparison of the stride length characteristics of both good and elite distance runners the level of perceived exertion and lactate accumulation would have to be the same for all runners. A biomechanical comparison at the point of each runner's anaerobic threshold or maximal steady state would be ideal since each subject's plasma lactate accumulation would be equivalent under these physiological conditions.

Stride Length in Relation to Height and Leg Length

In the present study no signficiant correlations were found between stride length while running at 85 percent of the aerobic capacity and the following anatomical variables: leg length (r = 0.528), and total body height (r = 0.562). There was also not a significant correlation reported between stride length while running at 70 percent of the aerobic capacity and total body height (r = 0.567). Although, the correlations discussed above were nonsignificant the coefficients of these correlations were approaching the significance level (r = 0.632). A significant correlation (r = 0.648) was reported between stride length at the running intensity of 70 percent of the aerobic capacity and leg length.

Elliot and Blanksby (1979) found that there were significant correlations between stride length and leg length at running speeds of 3.5 meters/sec., 4.5 meters/sec., and 5.5 meters/sec. in male recreational runners. The authors also found significant correlations between stride length and total body height at running speeds of 4.5 meters/sec. and 5.5 meters/sec. These findings led the authors to conclude that both height and leg length were important factors to consider when determining an optimal stride length for the recreational long distance runner.

Three relatively high but nonsignificant correlations were reported in the present study between stride length, leg length, and total body height. One significant correlation was found between leg length and stride length while running at 85 percent of the aerobic capacity. It is somewhat surprising that a group of highly trained distance runners such as the athletes in the present study did not use stride lengths that were closely related to their leg lengths or total body heights. One explanation for the number of nonsignificant correlations reported in the present study between body height, leg length and stride length may be related to subject number two. This subject demonstrated the longest stride length even though he did not have the greatest leg length or total body height. When subject number two was eliminated from the study, significant correlations were found when stride length was correlated with total body height and leg length. It is also interesting to note that this same subject accumulated high concentrations of lactate at both submaximal running speeds. This finding supports the conclusion of Cavanagh and Williams (1982), that it may be mechanically more efficient to understride than to grossly overstride. Based on the findings of this study it is the conclusion of this author that leg length and total body height are important factors to consider when choosing optimal stride lengths for highly trained distance runners. That is, highly trained distance runners should use stride lengths that are closely related to their leg lengths and total body heights.

Maximal Oxygen Uptake in Relation to Running Speed

In the present study low correlations were reported between maximal oxygen uptake and running speed. A low correlation ($r = -0.070$) was found between aerobic capacity and running speed at 70 percent of the aerobic capacity. At the runnning intensity of 85 percent of the aerobic capacity a low correlation (r = -0.119) was reported between maximal oxygen uptake and running speed. These findings indicated that aerobic capacity was not a good predictor of running speed or performance in highly trained long distance runners.

The findings of the present study involving the relationship between maximal oxygen uptake and running speed were supported by the literature. Conley and Krahenbuhl (1980) found a very low correlation (r = 0.12) between maximal oxygen uptake and distance running performance. The authors concluded that maximal oxygen uptake was not a good predictor of distance running performance. Farrell et al. (1979) also reported low correlations between aerobic capacity and distance running performance. Based on the findings of the present study and previous research this author concluded that a large aerobic capacity is essential for successful long distance running, but aerobic capacity alone is not a strong enough variable to predict long distance running performance.

Plasma Lactate in Relation to Running Speed

In the present study submaximal plasma lactate accumulation was not as highly correlated with distance running performance as has been reported in previous studies. The only significant correlation (r = -0.630) discovered in the present study between treadmill speed and plasma lactate accumulation was between these two variables while running at 70 percent of the aerobic capacity. A low correlation (r = -0.367) was reported between plasma lactate accumulation and running speed at 70 and 85 percent of the aerobic capacity. A nonsignificant correlation was also found between plasma lactate accumulation and treadmill speed at 85 percent of the aerobic capacity (r = 0.483).

Several studies (Costill, 1970; Costill et al., 1973; Farrell et al., 1979) have reported very high correlations between plasma lactate accumulation at submaximal running intensities and distance running performance. The authors of these studies used a measure such as race pace or time to determine distance running performance, and then correlated submaximal plasma lactate concentrations with these values. In the present study the subjects were required to complete two submaximal runs at 70 and 85 percent of the aerobic capacity. The subsequent submaximal plasma lactate values obtained at each of the running intensities were then correlated with the running speeds during the testing procedures.

The differences between the present study and the literature concerning the relationship between submaximal plasma lactate accumulation and distance running performance is due to the differences in testing procedures. In the present study running speed at 70 and 85 percent of the aerobic capacity was used as a performance measure and was correlated with the submaximal plasma lactate concentrations. The relative submaximal running speeds in the present study were not accurate measures of distance running performance. Race pace or total time during a maximal long distance race is a much more accurate method of determining distance running performance. The low correlations found between plasma lactate accumulation and distance running performance in the present study are due to the techniques used to determine distance running performance.

Conclusions

Based on the findings of the present study and using relative running intensities of 70 and 85 percent of the aerobic capacity the conclusions are:

1. There are significant correlations between submaximal plasma lactate concentrations and stride length measures expressed as a percentage of leg length and total body height.
2. Stride length is determined to a large extent by the accumulation of plasma lactate at submaximal running speeds. The runners that accumulated the highest concentrations of plasma lactate during the submaximal runs also used the longest strides when stride length was expressed as a percentage of leg length and total body height.
3. Leg length and total body height are important measures to consider when determining optimal stride lengths for highly trained distance runners.
4. Maximal oxygen uptake is not highly correlated with distance running performance. Extremely high aerobic capacities are prevelant among highly trained distance runners, but a high maximal oxygen consumption is not a guarantee of distance running success.
5. Relative submaximal distance running speeds are not accurate measures of distance running performance.

Recommendations

Based on the findings of the present study it is recommended that future research comparing the biomechanical characteristics of good and elite distance runners utilize testing procedures that control the variability of lactate accumlation among the subjects. If the lactate levels are not held constant among the subjects then the differences in running technique between the good and elite runners may be due simply to differences in perceived exertion among the athletes and not due to differences in mechanical efficiency. The point at which anaerobic threshold occurs would be an ideal tool to use when comparing the biomechanical characteristics of long distance runners since plasma lactate concentrations and levels of perceived exertion should be virtually the same among the subjects.

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APPENDIX A

Bruce Graded Exercise Test

APPENDIX A

Bruce Graded Exercise Test

Stage	Minutes	Speed(mph)	Grade(%)
1	0-3	1.7	10
2	3-6	2.5	12
3	6-9	3.4	14
4	9-12	4.2	16
5	12-15	5.0	18
6	15-18	5.5	20
7	18-21	6.0	22

APPENDIX B

Subject Consent to Procedure

APPENDIX B

Subject Consent to Procedure

I, ________________, hereby authorize members of the Appalachian State University Health, Physical Education and Recreation Department, and their designated assistants, nurse and/or lab technician, to administer to me the physical performance tests and the medical analysis described in the following procedure: Each person will complete two separate testing sessions.

Procedure for session 1 is as follows: (3/19/84)

1) Body weight and height will be measured.

2) A treadmill run to exhaustion will be administered to determine maximal oxygen uptake.

Procedure for session 2 is as follows: (3/26/84)

1) Height, weight and trochanter height will be measured.

2) A resting blood sample will be drawn and analyzed for plasma lactate concentration.

3) A submaximal run at 70 percent of the aerobic capacity will be administered on the treadmill.

4) A five minute rest period will follow the submaximal run and at the end of this rest period another blood sample will be drawn and analyzed for plasma lactate concentration.

5) After the second blood sample is drawn a submaximal run at 80 percent of the aerobic capacity will be administered.

6) A five minute rest period will follow this submaximal run and at the end of the rest period a third and final blood sample will be drawn and analyzed for plasma lactate concentration.

A certified nurse or lab technician will be present during the second testing session to collect blood samples.

I am aware that certain discomforts are associated with the procedures described such as pain associated with the insertion of the needle for the purpose of drawing blood, and related soreness. I certify that I am in good health and have no medical or health problems which may limit my physical performance.

I have understood the above explanation of procedures and voluntarily agree to participate in this study.

Signed: ________________________

Date: ____________________

APPENDIX C

Subject Information Form

APPENDIX C

Subject Information Form

Name:______________________ Date/time first session:______________

Year in school:____________ Date/time second session:_____________

Height in inches:____________ Weight in lbs.:____________

Maximal Oxygen Uptake:_____________________ml/kg x min.

Trochanter Height:_______________________inches

Stride Length:___________________________inches

Stride length in relation to leg length:_______________

Stride length in relation to height:___________________

Plasma Lactate Accumulation: Resting__________

70% max.:__________

85% max.:__________

Heart Rate: (Maximal Treadmill Test)

Resting:__________

10 min.:__________

11 min.:__________

12 min.:__________

13 min.:__________

14 min.:__________

15 min.:__________

16 min.:__________

17 min.:__________

18 min.:__________

APPENDIX D

Raw Data of Maximal Oxygen Uptake and Blood Lactate Accumulation at Rest and at 70 and 85 Percent of the Aerobic Capacity

APPENDIX D

Raw Data of Maximal Oxygen Uptake and Blood Lactate Accumulation

at Rest and at 70 and 85 Percent of the Aerobic Capacity

Subject	Aerobic Capacity ml/kg * min	Blood Lactate Accumulation millimoles/ml Rest	70%	80%
1	68.9	1.3	1.5	2.4
2	70.6	1.3	2.2	4.2
3	65.8	1.2	1.7	4.2
4	67.3	0.6	0.8	1.2
5	66.2	0.3	0.7	2.0
6	65.7	1.4	2.0	4.0
7	64.9	0.9	1.0	2.0
8	64.0	1.3	1.4	2.0
9	66.9	1.8	1.2	1.8
10	68.1	1.2	1.5	2.0

APPENDIX E

Stride Length and Running Speed at

70 and 85 Percent of the Aerobic Capacity

APPENDIX E

Stride Length and Running Speed at

70 and 85 Percent of the Aerobic Capacity

	Stride Length (inches)		Running Speed (mph)	
Subject	70%	85%	70%	85%
1	55.43	63.14	9.94	11.15
2	64.79	73.37	9.16	10.65
3	54.84	62.08	8.90	10.37
4	55.25	58.45	9.50	10.45
5	57.74	60.31	10.56	11.48
6	58.70	66.37	9.38	10.89
7	61.20	70.26	9.61	11.46
8	60.70	68.60	9.60	11.16
9	55.14	62.24	9.38	10.84
10	62.55	71.63	9.69	11.38

APPENDIX F

Raw Data of Stride Length to

Leg Length and Stride Length to Height Ratio

APPENDIX F

Raw Data of Stride Length to Leg Length

and Stride Length to Height Ratio

	Stride Length/Leg Length		Stride Length/Height	
Subject	70%	85%	70%	85%
1	0.65	0.57	1.29	1.13
2	0.58	0.51	1.08	0.95
3	0.67	0.59	1.23	1.08
4	0.67	0.63	1.27	1.19
5	0.67	0.64	1.19	1.14
6	0.62	0.54	1.13	1.00
7	0.64	0.56	1.19	1.09
8	0.65	0.57	1.21	1.07
9	0.65	0.58	1.22	1.08
10	0.65	0.57	1.20	1.05

APPENDIX G

Raw Data of Total Body Weight, Height, and Leg Length

APPENDIX G

Raw Data of Total Body Weight, Height, and Leg Length

Subject	Weight (lbs.)	Height (inches)	Leg Length (inches)
1	147.0	70.5	36.5
2	140.5	70.0	37.6
3	132.5	67.5	36.7
4	136.0	70.0	37.0
5	146.0	69.0	38.8
6	136.0	66.5	36.2
7	139.0	73.0	39.0
8	142.5	73.3	39.3
9	140.5	67.5	35.9
10	160.0	75.0	40.8

VITA

John Milton Seymour was born in Sodus, New York on November 5, 1957. He graduated from Red Creek Central School in Red Creek, New York on June 6, 1976. In August, 1980, he graduated from the State University of New York College at Brockport, Brockport, New York with a Bachelor of Science degree in Physical Education. After graduation he taught high school at Hannibal Central High School, Hannibal, New York. Then in 1982 he entered Appalachian State University as a graduate student working toward a Master of Arts degree in Exercise Science. The author was a teaching and laboratory assistant while at Appalachian State University.

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