THE UNIVERSITY OF MANITOBA

A COMPARISON OF THE PHYSIOLOGIC RESPONSE IN TRAINED MALES TO TWO MAXIMAL TREADMILL PROTOCOLS

by

Suzanne L. Rocan

A Thesis
Submitted to the
Faculty of Graduate Studies in partial fulfillment
of the requirements for the degree of
Master of Physical Education

School of Physical Education

January, 1982

A COMPARISON OF THE PHYSIOLOGIC RESPONSE IN TRAINED MALES TO TWO MAXIMAL TREADMILL PROTOCOLS

BY

SUZANNE L. ROCAN

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF PHYSICAL EDUCATION

ABSTRACT

The purpose of this study was to compare submaximal and maximal physiologic responses in trained males to two maximal treadmill protocols. The two protocols used were the progressive steady-state protocol (3 minute stages) and continuous protocol (1 minute stages). Each work load of the progressive steady-state protocol was set as every third work load of the continuous protocol. Eleven volunteer trained male subjects ($\bar{x}$ age = 27 years) participated in the study.

The Beckman Metabolic Cart was used to measure the following variables every 30 seconds throughout the test protocols: $\dot{V}_{O2}$ (STPD), $\dot{V}_{CO2}$ (STPD), $\dot{V}_E$ (BTPS) and R. An electrocardiographic strip was recorded every minute and at maximum to determine heart rate. Anaerobic threshold was determined using respiratory variables.

The results showed that there was a significant difference ($p<0.01$) in the length of the tests, with the progressive steady-state protocol being approximately one and a half minutes longer. No significant differences were found for the maximal values of $\dot{V}_{O2}$, $\dot{V}_{CO2}$, $\dot{V}_E$ and R. Significant differences were found for the following submaximal values: $\dot{V}_E$, $\dot{V}_{CO2}$ and R. The anaerobic threshold was detected at the same point on the two protocols using the various respiratory variables.

It was concluded that the maximal physiologic response to

the two protocols was not different, but at various submaximal levels, differences were found. The two criteria found to be best to detect anaerobic threshold were $\dot{V}_E/\dot{V}_{O_2}$ and F_EO_2. It is recommended that a standardized method for detecting the anaerobic threshold on the treadmill be established.

ACKNOWLEDGEMENTS

The author would like to thank her thesis committee, Dr. W. Dahlgren, Dr. M. Alexander and Dr. D. Mymin for their assistance and guidance. A special thank you to my advisor, Dr. Wendy Dahlgren for not only her expertise and encouragement but also for the confidence she bestowed upon me.

Thank you to Sharon Deminiac for technical assistance and Paul Thiessen for his help with the computer graph plotting and programs.

Acknowledgement is extended to all those who helped me in one way or another, from those who served as subjects, to those who were behind me for encouragement. You have all helped complete this study.

DEDICATION

To you Mom, I dedicate my thesis. Thank you for all your patience and never-ending encouragement.

CONTENTS

Page

TABLES

FIGURES

Chapter 1

INTRODUCTION

Maximum oxygen uptake ($\dot{V}_{O_2}$ max) is used to measure the ability of the cardiovascular system to deliver O_2 to satisfy aerobic requirements (Bruce, Kusumi & Hosmer, 1975; Mitchell & Blomqvist, 1971; Taylor, Wang, Rowell & Blomqvist, 1963; Balke & Ware, 1959). "The maximal oxygen consumption is the most important conditioning factor and most reliable criterion for the maximal (aerobic) physical performance" (Mellerowicz & Smodlaka, 1981, p. 320). It has been found to be dependent on cardiac output and A-V_{O_2} difference (Mitchell, Sproule & Chapman, 1958). In the absence of pulmonary pathology "the maximum oxygen uptake per kilogram of body weight will be roughly proportional to the cardiac output at the level of work required to elicit the maximum oxygen uptake" (Taylor et al., 1963, p. 718). $\dot{V}_{O_2}$ and work load have a linear relationship until a higher work load fails to increase $\dot{V}_{O_2}$ from the previous work load. This point is regarded as $\dot{V}_{O_2}$ max (Froelicher, Brammell, Davis, Noguera, Stewart & Lancaster, 1974; Mitchell & Blomqvist, 1971; Taylor et al., 1963; Taylor, Buskirk & Henschel, 1955). In addition "the cardiac output must be close to maximal and the A-V_{O_2} difference must also be very close to the maximum attainable under conditions of physical activity" (Taylor et al., 1963, p. 710).

With the increasing number of maximal tests being done, many protocols have been established to make a more convenient test for the subjects as well as for the laboratory staff. Wolthius, Froelicher, Fischer, Noguera, Davis, Stewart & Triebwasser (1977) stated that the needs of the subject, laboratory technician and the clinician must all be met when developing a protocol. The test must first of all be safe and easily adaptable for the subject (Wolthius et al., 1977; Bruce et al., 1975). Wolthius et al. (1977) stated that "moderate and even changes in treadmill grade are less likely to compromise the subject performance than are large changes in work load or uneven work load intervals, or both" (p. 697). For the laboratory technician, a protocol that requires minimal adjustment to reduce possible errors is needed (Wolthius et al., 1977). The clinician wants a test which lessens motion artifacts that may affect the electrocardiogram and blood pressure monitoring (Wolthius et al., 1977; Froelicher, Thompson, Noguera, Davis, Stewart & Triebwasser, 1975). Another requirement most investigators are concerned with is time. A maximal test that requires minimal time is advantageous for a laboratory that tests many people daily (Bruce et al., 1975).

The physician and exercise physiologist look at different aspects of the maximal test. The exercise physiologist looks at the cardiorespiratory responses and physiological equilibrium in healthy, normal individuals and tries to obtain maximal physiological responses (Barry, Webster & Daly, 1969; Taylor et al., 1955). The physician is more concerned with obtaining signs and symptoms of coronary heart disease.

An important consideration is the instrumentation for testing. If information on the O_2 transport system is wanted, the test chosen must use large muscle groups (Aström & Jonsson, 1976; Bruce et al., 1975). The two most widely used tests employ the bicycle ergometer and the treadmill (Bruce et al., 1975; Stamford, 1975). In comparing these two tests, the maximal treadmill test has been found to have certain advantages over the bicycle ergometer. First of all, the treadmill regulates energy expenditure, therefore giving it good reproducibility (Shephard, 1977; Fortuin & Weiss, 1977; McKay & Bannister, 1976; Bruce et al., 1975; Bruce, Blackman, Jones & Strait, 1963). "Most evidence supports the view that effort on the bicycle is limited by weakness of the most active muscles rather than by general exhaustion" plus "there is a pooling of blood in parts of the body that are immobilized" (Shephard, 1977, pp. 113 & 114). This pooling will produce local fatigue in the legs, which will cause the test to end before the O_2 transporting systems have been fully taxed (Astrand & Rodahl, 1977). "The treadmill is recommended for able-bodied subjects who are capable of walking or running on the treadmill, especially for testing the actual maximal $\dot{V}_{O_2}$ and for conditioning normal subjects and reconditioning patients" (Mellerowicz & Smodlaka, 1981, p. 390). It has been found that the subject reaches the highest values of $\dot{V}_{O_2}$ max on the treadmill as opposed to the bicycle ergometer (Mellerowicz & Smodlaka, 1981; Miyamura, Kitamura, Yamada & Matsui, 1978; Bruce et al., 1975; Hermansen & Saltin, 1969; Shephard, Allen, Benade, Davies, DePrampero, Hedman, Merriman, Myhre & Simmons, 1968).

The more popular treadmill protocols have either one minute (continuous) or three minute (progressive steady-state) stages. The continuous protocol utilizes small increments in work load until maximum. The progressive steady-state protocol, with a greater increment in work load from stage to stage, allows more time for physiologic adaptations. The continuous protocols have the advantage of bringing a subject gradually to exhaustion but have the disadvantage in the longer duration of the test before reaching maximum (Falls & Humphrey, 1973). Bruce et al. (1975) stated that a test for $\dot{V}_{O_2}$ max should allow time for physiologic adaptations and noted (1963) that "three minute periods of submaximal exertion provide the optimal compromise between requirements for physiological adaptations and minimal time for expeditious testing" (p. 753). There is some question regarding whether a one minute stage is long enough for this adaptation to take place. Balke & Ware (1959), who use a one minute stage protocol, stated that "the increase of work intensity is so gradual that functional adaptations take place within a few seconds. Thus, there is hardly any difference between the functional values measured during 'steady-state' work at comparable gradients" (p. 676). The proposed research compared a treadmill protocol with one minute incremental stages (continuous) to a protocol with three minute stages (progressive steady-state) to see if at equal work loads, the same metabolic measurements will be obtained.

Statement of the Problem

The main purpose of this study was to examine and compare continuous versus progressive steady-state maximal treadmill test protocols. More specifically, three particular objectives were sought: 1) to determine if particular submaximal work loads on the modified Balke-Ware (one minute stages) were equal to the same work load as measured by $\dot{V}_{O_2}$ on a progressive steady-state protocol; (three minute stages); 2) to determine if the two maximal treadmill protocols resulted in the same $\dot{V}_{O_2}$ max values; 3) to determine when the anaerobic threshold occurred in the two types of protocol.

Delimitations

1. Only twelve subjects were used because of the time and cost of the laboratory staff and equipment at the Kinsmen Reh-Fit center.

2. The twelve subjects were volunteers. The subjects had to be available for three maximal treadmill tests within two weeks.

3. The subjects were trained males.

Definitions

Anaerobic Threshold. As used in this study, refers to "the level of work or O_2 consumption just below that at which metabolic acidosis and the associated changes in gas exchange occur" (Wasserman, Whipp, Koyal & Beaver, 1973, p. 236).

Continuous Maximal Treadmill Protocol. As used in this study, is a maximal stress test protocol with one minute work loads and gradual increments (eg: 2% increase in elevation).

Modified Balke-Ware. As used in this study, this protocol has increments of 2% in elevation as opposed to the Balke-Ware protocol which has 1% increments.

Progressive Steady-State Maximal Treadmill Protocol. As used in this study, is a maximal stress test protocol with three minute work loads and larger increments (eg: 6% increase in elevation).

Chapter 2

REVIEW OF LITERATURE

This chapter contains a review of literature of the following: 1) control of variables, 2) attainment of maximal oxygen uptake, 3) anaerobic threshold, 4) steady-state, and 5) continuous versus progressive steady-state protocols.

Control of Variables

Due to many possible external factors that may affect test results, standardization must be established. It has been shown that "submaximal work pulse rates can be markedly affected by: a) temperature; b) meals, c) previous exercise and the time of day; and d) emotion. The maximum oxygen uptake appears to be relatively free of these factors" (Taylor et al., 1963, p. 712). It has been documented that if a light meal is ingested, things such as "butter, cream, coffee, tea or alcohol should be avoided (Ellestad, Blomqvist & Naughton, 1979, p. 423). Taylor et al. (1955) have shown that a small meal of about 750 calories had little or no effect on the results for $\dot{V}_{O_2}$ max. For best results, the temperature of the environment should also be controlled (Ellestad et al., 1979; Taylor et al., 1955). "No difference was found in maximal oxygen uptake between 62° and 78°, while the decrease at 110° was of the order of magnitude of 6%" (Taylor et al., 1963, p. 713). Other controls used in this study included abstaining from smoking one hour before the test and avoiding strenuous activity the day of the test (Shephard, 1977).

Attainment of Maximal Oxygen Uptake

Various investigators used different criteria to determine when a true $\dot{V}_{O_2}$ max is reached. Heart rate has been used as a guideline. Balke & Ware (1959) state that a pulse rate of 180 beats per minute or more signifies a maximal test but in a small number of cases this attainment is impossible. Others said that "in the absence of clinical end points or limiting leg fatigue, the target heart rate achieved should be at least 85% of the estimate for the subject's age based on the maximal heart rate data available" (Ellestad et al., 1979, p. 425). Respiratory gas exchange ratio values above one have also been used as a criterion (Taylor et al., 1955) but the most commonly used criterion for determining $\dot{V}_{O_2}$ max has been the levelling off or decrease in $\dot{V}_{O_2}$ with an increase in work load. With progressively increasing work loads, there is a linear relationship between $\dot{V}_{O_2}$ and work load (Mitchell et al., 1958; Taylor et al., 1955). When $\dot{V}_{O_2}$ max is reached, any further increase in work load will fail to increase $\dot{V}_{O_2}$ (Mitchell & Blomqvist, 1971; Taylor et al., 1963). At this time, $\dot{V}_{O_2}$ levels off or declines (Mitchell et al., 1958). "It is clear that at this point the cardiac output must be close to maximal and the A-VO_2 difference must also be very close to the maximum attainable under conditions of physical activity" (Taylor et al., 1963, p. 710). "Further increases in work load beyond this point merely result in an increase in oxygen debt and a shortening of the time in which the work can be performed " (Taylor et al., 1955, p. 78).

Anaerobic Threshold

The anaerobic threshold is defined as "the level of work or O_2 consumption just below that at which metabolic acidosis and the associated changes in gas exchange occur" (Wasserman et al., 1973, p. 236). This point of metabolic acidosis occurs when the aerobic energy production is not able to fulfill the requirements of the exercise any more (Rusko, Rahkila & Karvinen, 1980; Wasserman & McIlroy, 1964). It has been found that the measurement of respiratory variables is a valid and reliable indirect method to detect the anaerobic threshold without blood samples during incremental exercise (Davis, Vodak, Wilmore, Vodak & Kurtz, 1976).

The use of respiratory variables has allowed us to detect the anaerobic metabolism in many ways (refer to Figure 1). For this study, the following commonly used criteria were used: 1) the initial abrupt increase in the ventilatory equivalent for O_2 ($\dot{V}_E/\dot{V}_{O_2}$) without an increase in the ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}_{CO_2}$), 2) the initial point of departure from linearity in the expiratory minute volume or ventilation ($\dot{V}_E$-BTPS) 3) the initial abrupt increase in the fraction of expired O_2 (F_EO_2) and, 4) a steeper increase in the respiratory gas

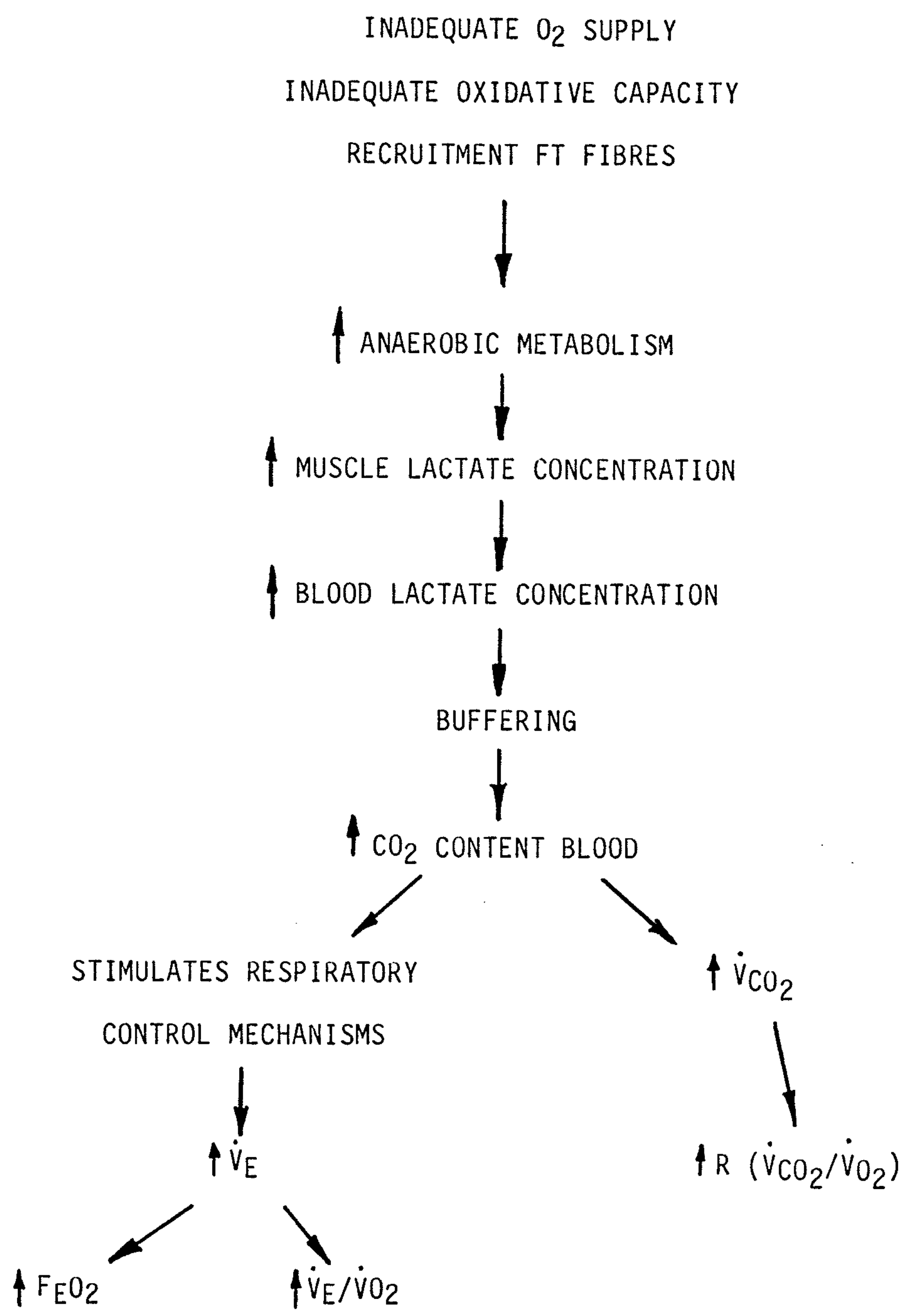


Figure 1
Schematic illustration outlining the determination of the anaerobic threshold using key ventilatory and gas exchange indices (i.e. $\dot{V}_E$, $\dot{V}_{CO_2}$, R, F_EO_2, $\dot{V}_E/\dot{V}_{O_2}$)
(Prietto, Caiozzo, Ellis, Davis & McMaster, 1981).

exchange ratio (R), all plotted against time.

$\dot{V}_E/\dot{V}_{O_2}$ has been found to be one of the easiest measures to detect the anaerobic threshold (Prietto et al., 1981; Davis, Frank, Whipp & Wasserman, 1979). Once the content of CO_2 in the blood increases due to the buffering of lactic acid, $\dot{V}_{CO_2}$, R and $\dot{V}_E$ increase leading to an increase in $\dot{V}_E/\dot{V}_{O_2}$. At the point where $\dot{V}_E/\dot{V}_{O_2}$ increases from a generally flat slope (anaerobic threshold), greater volumes of air are being taken in for the absorption of equal amounts of O_2 (Mellerowicz & Smodlaka, 1981). "The magnitude of the $\dot{V}_E/\dot{V}_{O_2}$ is dependent on constitutional factors, especially morphological condition of the respiratory system, age, sex and especially of ventilation" (Mellerowicz & Smodlaka, 1981, p. 230).

$\dot{V}_E$ increases linearly to the work load until the anaerobic threshold is reached, at which time there is a nonlinear increase (Wells & Haan, 1981; Prietto et al., 1981; Rusko et al., 1980; Weltman, Katch, Sady & Freedson, 1978; MacDougall, 1977; Davis et al., 1976; Wasserman et al, 1973). The additional CO_2 content of the blood at metabolic acidosis (anaerobic threshold), stimulates the respiratory control mechanisms which in turn increases $\dot{V}_E$.

The anaerobic threshold is easy to discern from F_EO_2 (as is $\dot{V}_E/\dot{V}_{O_2}$) because of the increase from a generally flat slope (Prietto et al., 1981). "The problem with using $\dot{V}_E$, $\dot{V}_{CO_2}$ and R to discern the anaerobic threshold is that they are already increasing due to the ventilatory and metabolic requirements of the incremental exercise; a further increase or steeper slope is often difficult to detect" (Prietto et al., 1981, p. 14). "The extra increase in $\dot{V}_E$ results in a lower extraction of O_2 per volume of air ventilated and there is a corresponding rise in F_EO_2" (Skinner & McLellan, 1980, p. 236).

R is the ratio of $\dot{V}_{CO_2}$ over $\dot{V}_{O_2}$. As the work loads increase, so does R. "The rapidity of this increase depends on intensity of the performance, age, sex and training of the subject" (Mellerowicz & Smodlaka, 1981, p. 251). The sudden steeper increase in R "reflects the formation of acids (chiefly lactic acid) through the release of CO_2 from bicarbonate" (Naimark, Wasserman & McIlroy, 1964, p. 650). When there is an extreme rise in lactic acid (anaerobic threshold) there is a high rate of CO_2 production and expulsion making R rise to 1.0 or higher (Mellerowicz & Smodlaka, 1981). Recent studies have shown R to be the least sensitive of all methods (Davis et al., 1976; Wasserman et al., 1973) but it can still be helpful in some cases if used in combination with other means of detecting the onset of anaerobic metabolism.

Anaerobic Threshold in the Trained versus Untrained Subjects

The O_2 value or percent of $\dot{V}_{O_2}$ max at which the anaerobic threshold occurs depends on the level of fitness of the subject (refer to Table 1). The trained individual seems to reach the anaerobic threshold at a higher percentage of $\dot{V}_{O_2}$ max. It

Table 1

Anaerobic Threshold Values in Various Populations

STUDY	ACTIVITY	N	ANAEROBIC THRESHOLD $\dot{V}O_2$	ANAEROBIC THRESHOLD % $\dot{V}O_2$ max
Prietto et al. (1981)	Middle and Long Distance Runners	8	62.5 $\pm$ 4.3 ml/kg/min	77
Wells & Haan (1981)	Male Marathon Runners	9	2.252 l/min	57.6
	Female Marathon Runners	8	1.794 l/min	65.3
Rusko et al. (1980)	Female Cross-Country Skiers	15	40.9 ml/kg/min	86
Davis et al. (1979)	Untrained Males	9	1.36 $\pm$ .10 l/min	49.4 $\pm$ 2.6
	After 9 week endurance program	9	1.96 $\pm$ .10 l/min	57 $\pm$ 2.1
Weltman et al. (1978)	Untrained Females	28	1.11 $\pm$ .25 l/min	49
			18.1 $\pm$ 5.4 ml/kg/min	57 $\pm$ 2.1
Davis et al. (1976)	Untrained Males	30	2.43 $\pm$ .29 l/min	58.6 $\pm$ 5.8
Costill (1970)	Distance Runners	11		> 70

appears that the anaerobic threshold can be used as a measure of submaximum fitness. Weltman et al. (1978) have shown that even though two people have identical $\dot{V}_{O_2}$ max values, their anaerobic threshold values are not necessarily identical. "This might explain why endurance perfomance can continue to improve while $\dot{V}_{O_2}$ max remains unchanged" (Prietto et al., 1981, p. 15).

Steady-State

"The steady level of oxygen uptake which is achieved during exercise is generally accepted as reflecting the energy cost of the exercise" (Stainsby & Barclay, 1970, p. 178). The energy needed during continued muscular activity which establishes the steady-state of $\dot{V}_{O_2}$ is due to the metabolism turnover and contractile activity (Stainsby & Barclay, 1970). Many maximal treadmill test protocols are designed to achieve a steady-state at submaximal work loads so one can predict $\dot{V}_{O_2}$ at any given stage. The criteria set for a steady-state is when the heart rate remains within five beats per minute and 0.1% in the mixed expired concentrations of O_2 and CO_2 (Sutton, 1979). It has been documented that the rate of reaching a steady-state level is affected by work intensity and the physical fitness of the subject (Wasserman, Van Kessel & Burton, 1967; Wasserman & McIlroy, 1964). Hughson, Kowalchuk, Prime & Green (1980) found that $\dot{V}_{O_2}$ goes through three stages to adapt to exercise. "There is a rapid initial increase of 200-300% in the first few breaths, a progressive increase, and a plateau or 'steady-state' condition (Hughson et al., 1980, p. 18). O_2 will continue to rise at a declining rate until a steady-state is reached (Stainsby & Barclay, 1970). It has been found that a steady-state level for $\dot{V}_{O_2}$ is usually established at about the third minute at a given lower work load (Fardy & Hellerstein, 1978; Fernandez, Mohler & Butler, 1974; Wasserman et al., 1973; Montoye, Guber, Cunningham & Dinka, 1970; Cotes, Allsopp & Sardi, 1969; Wasserman & McIlroy, 1964). At higher work loads, the time needed to achieve a steady-state is delayed above the anaerobic threshold (Wasserman et al., 1973; Cotes et al., 1969; Wasserman & McIlroy, 1964). Some studies show that at the highest work rates, a true steady-state is not reached by the sixth to tenth minute (Wasserman et al., 1967; Wasserman & McIlroy, 1964). "Exercise above the anaerobic threshold results in altered O_2 uptake kinetics, with a delay in the O_2 uptake steady-state time and an increase in the O_2 deficit and debt" (Wasserman et al., 1973, p. 236). But for the purpose of maximal treadmill protocols, Bruce et al. (1963) found that "three minute periods of submaximal exertion provide the optimal compromise between requirements for physiological adaptations and minimal time for expeditious testing" (p. 753).

Steady-State in Trained Individuals

It seems accepted that the increase in $\dot{V}_{O_2}$ during an incremental exercise test is not only affected by the relative work rate, but also by the trained state of the individual (Hickson, Bomze & Holloszy, 1978). Many studies have shown that in the trained individual, a steady-state is reached at a faster rate at the same relative and absolute submaximal work loads (Hagberg, Hickson, Ehsani & Holloszy, 1980; Hickson et al., 1978; Weltman et al., 1978; Weltman & Katch, 1976). It appears that endurance training allows an individual to reach a steady-state at a faster rate because $\dot{V}_{O_2}$ meets the O_2 demand more rapidly, therefore there is less of an O_2 deficit (Hagberg et al., 1980; Hickson et al., 1978; Weltman et al., 1978). At the same absolute intensity, the trained individual employs less anaerobic oxidation as compared to the untrained individual (Hickson et al., 1978; Wasserman et al., 1967; Wasserman & McIlroy, 1964). Hagberg et al. (1980) found that "CO_2 production also adjusted toward the steady-state more rapidly in the trained than the untrained state" (p. 220). At equal work loads, the $\dot{V}_{CO_2}$ of the trained individual is less (Mellerowicz & Smodlaka, 1981). Trained males were used for this study.

Continuous versus Progressive Steady-State Protocols

Many maximal treadmill stress test protocols exist today. Researchers are constantly trying to develop the best protocol for the subject as well as the experimenter. The two treadmill protocols this experimenter was concerned with were the continuous and the progressive steady-state protocols. While some research has been done on the comparison of maximal values obtained from these two protocols, little has been done on the comparison of submaximal stages.

Froelicher et al. (1974) stated that "the small incremental steps of the Balke protocol produce the same cardiovascular effect in a longer period as the greater incremental stages of the shorter Bruce test" (p. 516). (The Balke test is a continuous protocol while the Bruce test is a progressive steady-state protocol). They found no significant differences in $\dot{V}_{O_2}$ max and maximum heart rate.

Froelicher et al. (1975) compared the Bruce and Balke treadmill protocols to determine whether they were accurate in predicting $\dot{V}_{O_2}$ max. The results showed no significant difference in the maximal heart rate between the two protocols. The mean maximal R, $\dot{V}_E$, and $\dot{V}_{O_2}$ were significantly greater in the Bruce protocol. "The mean maximal treadmill time was significantly greater in the Balke protocol as compared to the Bruce protocol" (Froelicher et al., 1975, p. 333).

Pollock, Bohannon, Cooper, Ayres, Ward, White & Linnerud (1976) found that "the rate of increase in $\dot{V}_{O_2}$ and heart rate was different" (p. 46) between the Balke and Bruce protocol, but there were no significant differences in $\dot{V}_{O_2}$ max and maximum heart rate. The maximal $\dot{V}_E$ and R were found to be significantly lower in the continuous protocol suggesting possibly a different breathing pattern. There was also a significant difference in treadmill time.

An advantage with the continuous protocol is that the first few work loads can be used as a warm-up (Aström & Jonsson, 1976).

As found by the previously mentioned investigators, a disadvantage is that a longer period of time is needed to reach exhaustion (Falls & Humphrey, 1973).

This study looked at the metabolic measurements obtained at comparable gradients to see if there were any significant differences between the two types of protocols.

Chapter 3

METHODS AND PROCEDURES

Subjects

Twelve male volunteer subjects between the ages of 17 and 47 years ($\bar{x}$=27) participated in the study (Table 2). Only eleven were able to complete the number of tests required. The number of subjects was a limitation but "the measurement of oxygen consumption requires the collection and analysis of expired air which is both costly and tedious" (Froelicher et al., 1975, p. 331). The subjects were known to be more fit than the average population from previous testing or training. Each subject answered a physical activity readiness questionnaire (Par-Q), signed a consent form, and received an information sheet prior to undergoing any testing procedure (refer to Appendix A).

Procedures

Instructions to Subjects

Because many factors may affect the test results, the subjects were given an information sheet to ensure some standardization (refer to Appendix A). The controls were: 1) temperature, 2) time of test, 3) ingestion of food, and, 4) previous exercise.

Table 2

Physical Parameters of the Eleven Volunteer Subjects

Subject No.	Age (yrs)	Ht. (cm)	Mean Wt. (kg)	Protocol 1 and 2									
				VO_2 Max (1/min)		VO_2 Max (ml/kg/min)		AT (% VO_2 max)		AT (1/min)		AT (ml/kg/min)	
1	28	177	75.6	4.05	4.33	53.3	57.4	73.8	62.8	2.99	2.72	53.5	36.0
2	47	174.5	70.3	3.10	3.18	43.9	45.3	75.2	61.0	2.33	1.94	33.1	27.6
3	29	176	64.1	3.82	3.64	59.8	56.7	69.9	59.1	2.67	2.15	41.9	33.4
4	17	168.5	63.6	3.62	3.34	56.7	52.8	74.9	89.2	2.71	2.98	42.4	47.2
5	26	188	89.0	4.51	4.40	51.0	49.3	85.6	84.5	3.86	3.72	43.6	41.7
6	24	168	62.4	3.73	3.59	60.1	57.7	77.2	70.2	2.88	2.52	46.4	40.6
7	27	175	73.7	3.98	4.06	54.0	55.4	65.8	75.1	2.62	3.05	35.6	41.6
8	21	181	81.5	4.58	4.78	56.5	59.3	67.2	81.6	3.08	3.90	38.0	48.8
9	34	175	65.2	3.20	3.33	49.2	51.2	88.8	85.3	2.84	2.84	43.6	43.7
10	21	167	70.2	5.04	4.02	71.5	57.6	67.9	78.9	3.42	3.17	48.5	45.5
11	27	175	65.4	4.07	4.12	63.1	62.4	78.4	77.9	3.19	3.21	49.4	48.6

Pre-Test Protocol

Height and weight were taken upon the arrival of the subject. The leads were then placed on their chest. The subjects then sat for five minutes to determine resting $\dot{V}_{O_2}$ and to allow familarization with the mouthpiece. Because many subjects tend to hyperventilate before a maximal test (Mellerowicz & Smodlaka, 1981), the five minute resting period allowed $\dot{V}_{CO_2}$ to drop to an R of between 0.80 and 0.90. After this five minute period, a resting blood pressure was taken. The subject was then permitted to stretch. When the subject indicated that he felt ready, the maximal test was started.

Test Protocols

The two treadmill tests performed were the modified Balke-Ware (continuous protocol) and a test with three minute stages (progressive steady-state protocol) (refer to Appendix B). An electrocardiographic strip, weight, height and blood pressure were recorded before starting.

The modified Balke-Ware (protocol 1) began with a warmup (on the treadmill) of two minutes, one minute at 2.4 km. at 0 elevation and the second minute at 3.2 km. at 0 elevation. If the subject (by observation of the investigator) had not adjusted to the treadmill, this warmup period was extended. The actual test began at a 2% elevation at 5.4 km. and increased by a 2% elevation every minute. If the test exceeded a 25% elevation (which is the treadmill's maximum), the elevation was then maintained and the speed was increased by .3 km. every minute. The subjects were not allowed to use the treadmill handrails for support at any time during the actual testing procedure. R, $\dot{V}_E$ (BTPS), $\dot{V}_{CO_2}$ (STPD) and $\dot{V}_{O_2}$ (STPD) were calculated as mean values of 30 second periods (other measurements and calculations were made, but these variables were the ones of interest to this study. Refer to Appendix C).

An electrocardiographic strip was recorded at the end of every minute and at maximum to determine the heart rate. It was also recorded at the end of every minute in the six minute recovery period. For the second protocol, each work load was set as every third work load of the first protocol and was three minutes in duration (refer to Appendix B). The rest of the description and procedures are identical to those previously given.

There were three criteria used to determine whether the maximal work capacity had been reached: 1) the heart rate was 180 beats per minute or more, 2) the subject could not keep up with the treadmill any longer and 3) a higher work load caused no increase or a slight decrease in $\dot{V}_{O_2}$ from the previous work load. Subjects were verbally encouraged to continue until exhaustion.

Design

Each subject performed three maximal tests; two maximal tests using one of the protocols and one maximal test on the second protocol, in a random order. This balanced the possible learning factors (Fardy & Hellerstein, 1978; Pollock et al., 1976). All testing on an individual was conducted during a two week period with the minimum time between any two consecutive tests being two days.

Data Analysis

Descriptive data was done on all variables recorded using the BMPD1D program. A graph of the averages of each steady-state variable at each work load of both protocols were plotted. In the case of a repeated test of the same protocol, the test used for data analysis was the one which had the highest $\dot{V}_{O2}$ max. The variables $\dot{V}_E$, R, $\dot{V}_{O2}$, $\dot{V}_{CO2}$ and heart rate were plotted against test duration. Plotting was done by the Hewlett Packard 9835A mini computer.

Spearman's rank correlation coefficient test was used to determine the reliability of the two protocols at the submaximal and maximal work loads.

Student's paired t-test was used to determine if there were significant differences between the submaximal and maximal level variables of the two protocols. Differences were considered significant at the $p<0.05$ level.

Values of $\dot{V}_E/\dot{V}_{O2}$, $\dot{V}_E$, F_EO_2 and R were plotted against test duration for each individual on both protocols. The criteria used to determine anaerobic threshold were: 1) the initial abrupt increase in $\dot{V}_E/\dot{V}_{O2}$ without an increase in $\dot{V}_E/$

$\dot{V}_{CO_2}$, 2) the initial point of departure from linearity in $\dot{V}_E$, 3) the initial abrupt increase in F_EO_2 and 4) a steeper increase in R. The onset of anaerobic threshold was determined from these graphs by visual inspection by the investigator and an expert in the field. The point agreed upon by these skilled observers was taken as the anaerobic threshold. The anaerobic threshold was expressed as $\dot{V}_{O_2}$ and the percentage of $\dot{V}_{O_2}$ max. Where there was a discrepancy between the various criteria, an average was taken. The means and standard deviations were calculated for each protocol.

The Student's paired t-test was then used to determine if there was a significant difference between the anaerobic threshold of the two protocols. Differences were considered significant at the $p<0.05$ level.

Equipment and Materials

The Beckman Metabolic Measurement Cart (MMC) which contains an 1810 Monroe calculator, was used to determine all the gasometric measurements (refer to Appendix C). Froelicher & Lancaster (1974) observed that $\dot{V}_{O_2}$ max can differ widely among individuals for any given maximal treadmill time. "Thus, the accurate determinator of an individual's functional aerobic capacity or the indirect estimate of maximal cardiac output requires the actual measurement of O_2 consumption" (Froelicher & Lancaster, 1974, p. 449).

The MMC was calibrated before and after each test using calibration gases. The volume transducer was calibrated daily and checked between tests. The subjects had a rubber mouth-piece fitted with a Hans-Rudolph non-rebreathing pulmonary valve No. 2700 for collection of expired gases. Low-resistance and nonkinkable tubing extended from the valve to the MMC. During collection of expired air, the subject's nose was occluded by a clip. The O_2 was measured by a Beckman OM-11 analyzer and CO_2 by a Beckman LB2 analyzer. Because the O_2 analyzer is a partial pressure sensor and sensitive to the presence of water vapor (Wilmore et al., 1976), the tubing for gas collection was changed and the mixing chamber was opened and dried after each test. The Drierite (calcium sulfate) in the drying tube was also changed after each test for complete absorption of water vapor. A CM-1 lead configuration was used to monitor and record heart rate on a single channel recorder by Harco. Blood pressure was taken with a sphygmomameter. A calibrated Quinton treadmill was used for all testing.

Chapter 4

RESULTS AND DISCUSSION

The results and discussion are presented in the following sections: reliability, maximal work load, submaximal work loads and anaerobic threshold. Tables and graphical representations of the results are also presented.

Reliability

As previously mentioned, each subject repeated one of the maximal treadmill protocols (n=6 for protocol 1, n=5 for protocol 2) for the determination of reliability. Spearman rank correlation coefficients are presented in Tables 3 and 4. Relatively low correlation coefficients may be due to the small sample size which may not disguise the biological variation. Another reason may be the effect of extreme scores on the statistical analysis used.

The treadmill was calibrated for speed and elevation at the commencement of the study. Bruce et al. (1975) found that a calibrated, motor-driven treadmill has the advantage of being reproducible because "the rate of energy expenditure is regulated involuntarily (unless the subject or patient supports part of his body weight by leaning on the handrail)" (p. 557). The Beckman MMC was also calibrated before and after every test. Because the equipment used was reliable, the variation was most likely due to the subjects as opposed to the equipment.

Table 3

Reliability of Protocol 1
(Spearman Rank Correlation Coefficients N=6)

PHYSIOLOGICAL VARIABLES	STAGES 1	2	3	4	5	6	7	8	9	10	11	12	13	MAX
$\dot{V}_{O_2}$ (ml/kg/min)	.52	.94	.71	.65	.31	.65	.66	.60	.52	.00	.29	-.20	-1	.79
$\dot{V}_{O_2}$ (ml/min)	.66	.77	.49	.83	.49	.77	.80	.94	.98	.50	.85	.80	1	.94
HEART RATE	.92	.89	.93	.83	.98	.77	.87	1	.82	.61	.48	.92	1	.86
$\dot{V}_E$ (1/min)	.94	.77	.77	.77	.67	.94	.92	.89	1	.70	.90	.70	.5	.77
$\dot{V}_{CO_2}$ (ml/min)	.92	.67	.66	.94	.83	.86	.77	.71	1	.90	.90	.80	1	.94
R	.37	.72	.24	.14	.09	.68	.25	.55	.73	.80	.80	.95	.5	.79
TEST DURATION (seconds)														.94

Table 4

Reliability of Protocol 2
(Spearman Rank Correlation Coefficients N=5)

PHYSIOLOGICAL VARIABLES	STAGES 1	2	3	MAX
$\dot{V}_{O_2}$ (ml/kg/min)	-.10	.65	.50	.30
$\dot{V}_{O_2}$ (ml/min)	.20	.70	.80	.70
HEART RATE	-.70	.12	.20	.93
$\dot{V}_E$ (l/min)	.50	.50	.80	.80
$\dot{V}_{CO_2}$ (ml/min)	.50	.90	1	.90
R	.77	.60	.92	0
TEST DURATION (seconds)				.36

An attempt was made to reduce subject variability. Repeat tests done on an individual were scheduled at the same time of day, under the same environmental conditions. Further, the subjects were asked to follow the instructions on the information sheet (refer to Appendix A).

Maximal Work Load

Maximal physiological values for the two test protocols can be found in Table 5. No significant differences were found for maximal heart rate, $\dot{V}_{O2}$, $\dot{V}_E$, $\dot{V}_{CO2}$ and R. It appears that the two protocols were measuring the same values for the maximal variables. Test duration was found to be significantly greater in protocol one (0.01 level of significance).

Similar continuous protocols to that utilized were also found to be significantly longer in duration when compared to a progressive steady-state protocol (Pollock et al., 1976; Froelicher et al., 1975; Froelicher et al., 1974). Protocol one was approximately one and a half minutes longer yet, the maximal work load achieved was the same. Bruce et al. (1975) stated that one of the basic requirements of any test measuring $\dot{V}_{O_2}$ max is that it should "require minimal time for monitoring and supervising personnel yet provide substantial data" (p. 546). Both protocols resulted in the same maximal physiological values and work load, although the progressive steady-state protocol resulted in a slightly longer test duration. Even though the test duration was significantly

Table 5

Comparison of Maximal Parameters From Each Test Protocol

PHYSIOLOGICAL VARIABLES	CONTINUOUS Mean (±SD)	PROGRESSIVE STEADY-STATE Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ max (ml/kg/min)	56.12 (±6.7)	52.81 (±5.6)	- .86
$\dot{V}_{O_2}$ max (ml/min)	3925.88 (±565.5)	3797.50 (±511.6)	- .77
MAX HEART RATE (beats/min)	184.24 (±10.2)	182.62 (±12.7)	- .99
$\dot{V}_E$ max (liters/min-BTPS)	136.86 (±26.1)	135.04 (±21.9)	- .58
$\dot{V}_{CO_2}$ max (ml/min)	4519.98 (±700.2)	4476.23 (±638.1)	- .89
RESPIRATORY GAS EXCHANGE RATIO	1.15 (±0.1)	1.18 (±0.1)	.30
TEST DURATION (seconds)	758.82 (±139.4)	663.75 (±127.2)	-7.42 **

* $p<0.05$ $t_{.05} = 1.96$

** $p<0.01$ $t_{.01} = 2.576$

longer in protocol one, the opinion of the investigator is that the actual difference in time required to complete the test (approximately 1 1/2 minutes) does not in itself warrant the selection of one protocol over the other.

Submaximal Work Loads

Oxygen Uptake

The measurements for the submaximal work loads can be found in Table 6. Looking at $\dot{V}_{O_2}$, the only significant difference between the two protocols occurred at minute nine. When $\dot{V}_{O_2}$ was corrected for body weight, the difference was significant at a .01 level of significance, while absolute $\dot{V}_{O_2}$ was significant only at the .05 level. In both cases, $\dot{V}_{O_2}$ was higher in protocol two. At any other submaximal work load, no significant differences were found.

Froelicher et al. (1974) found that a given work load of the Balke protocol was equivalent in cardiovascular response to a comparable work load in the Bruce protocol. With a greater number of subjects, the difference found in this study may not have occurred. An extreme score could have caused the significant difference with the statistical analysis used (paired t-test). At minute nine, the mean $\dot{V}_{O_2}$ for protocol one and two makes little physiological difference. Taking the study's limitations into account, one could conclude that at equal work loads, both protocols resulted in the same $\dot{V}_{O_2}$.

Table 6

Comparison of Submaximal Parameters from Each Test Protocol

STAGE	CONTINUOUS	PROGRESSIVE STEADY-STATE	
3 minutes (6%-5.4 km)	Mean (±SD)	Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ (ml/kg/min)	24.91 (±1.9)	25.94 (±2.1)	-1.22
$\dot{V}_{O_2}$ (ml/min)	1759.09 (±169.8)	1838.18 (±192.3)	-1.28
HEART RATE (beats/min)	117.00 (±12.7)	118.64 (±17.9)	-0.04
$\dot{V}_E$ (liters/min-BTPS)	39.60 (±5.9)	44.56 (±5.3)	-3.64**
$\dot{V}_{CO_2}$ (ml/min)	1400.00 (±174.4)	1590.91 (±180.8)	-5.01**
R	0.80 (±0.0)	0.86 (±0.0)	-2.94**
6 minutes (12%-5.4 km)	Mean (±SD)	Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ (ml/kg/min)	34.84 (±1.3)	35.96 (±2.6)	-1.53
$\dot{V}_{O_2}$ (ml/min)	2469.09 (±283.2)	2551.82 (±295.0)	-1.47
HEART RATE (beats/min)	141.46 (±11.7)	147.73 (±17.6)	-2.42*
$\dot{V}_E$ (liters/min-BTPS)	58.43 (±9.0)	67.34 (±11.5)	-4.94**
$\dot{V}_{CO_2}$ (ml/min)	2233.64 (±319.3)	2479.09 (±364.0)	-4.12**
R	0.90 (±0.1)	0.97 (±0.1)	-2.62**
9 minutes (18%-5.4 km)	Mean (±SD)	Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ (ml/kg/min)	45.06 (±3.0)	46.90 (±3.5)	-2.70**
$\dot{V}_{O_2}$ (ml/min)	2184.54 (±334.9)	3335.00 (±428.6)	-2.56*
HEART RATE (beats/min)	167.91 (±14.1)	168.90 (±17.4)	-1.90
$\dot{V}_E$ (liters/min-BTPS)	89.86 (±16.4)	96.74 (±17.0)	-3.79
$\dot{V}_{CO_2}$ (ml/min)	3281.82 (±440.3)	3469.00 (±493.0)	-4.34**
R	1.03 (±0.1)	1.04 (±0.1)	-1.10**

* $p<0.05$ $t_{.05} = 1.96$

** $p<0.01$ $t_{.01} = 2.576$

Table 6 (continued)

STAGE	CONTINUOUS	PROGRESSIVE STEADY-STATE	
12 minutes (24%-5.4 km)	Mean (±SD)	Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ (ml/kg/min)	54.87 (±3.3)	54.13 (±3.0)	- .31
$\dot{V}_{O_2}$ (ml/min)	3852.86 (±430.8)	3773.33 (±264.1)	- .29
HEART RATE (beats/min)	178.71 (±11.8)	170.33 (±15.0)	- .21
$\dot{V}_E$ (liters/min-BTPS)	124.87 (±28.5)	123.53 (±23.4)	-3.15**
$\dot{V}_{CO_2}$ (ml/min)	4297.14 (±779.6)	4223.66 (±389.4)	-2.07*
R	1.11 (±0.1)	1.23 (±0.2)	-1.05
15 minutes (24%-6.3 km)	Mean (±SD)	Mean (±SD)	T-SCORE
$\dot{V}_{O_2}$ (ml/kg/min)	62.95 (±3.5)	59.75 (±3.8)	- .63
$\dot{V}_{O_2}$ (ml/min)	4260.00 (±495.0)	4050.00 (±99.0)	- .50
HEART RATE (beats/min)	179.00 (±12.7)	179.00 (±12.7)	0
$\dot{V}_E$ (liters/min-BTPS)	128.75 (±8.7)	139.35 (±10.8)	-7.07**
$\dot{V}_{CO_2}$ (ml/min)	4405.00 (±346.5)	4920.00 (±622.2)	-2.64**
R	1.04 (±0.0)	1.22 (±0.2)	-1.13

* $p<0.05$ $t_{.05} = 1.96$

** $p<0.01$ $t_{.01} = 2.576$

Figure 2 is an example of the rate of increase in relative $\dot{V}_{O2}$ in the two protocols for a single subject. Figure 3 is the rate of increase in relative $\dot{V}_{O2}$ of the eleven subjects in the two protocols. Protocol one showed a linear increase in $\dot{V}_{O2}$ throughout the test duration. In protocol two, there was a levelling off at the end of the first two work loads (minutes 3 and 6). This agrees with other studies which have shown that at lower work loads, a steady-state level for $\dot{V}_{O2}$ is usually established at about the third minute (Fardy & Hellerstein, 1978; Fernandez et al., 1974; Wasserman et al., 1973; Montoye et al., 1970; Cotes et al., 1969; Wasserman & McIlroy, 1964). At higher work loads, a true steady-state will not be established until the sixth to tenth minute (Wasserman et al., 1967; Wasserman & McIlroy, 1964) therefore a levelling off is not seen on the graph.

<u>Heart Rate</u>

There was a significant difference in heart rate only at minute six ($p<0.05$) when heart rate was higher in protocol two. Because there were no other differences at the other work loads and that the higher heart rate did not correspond to the higher $\dot{V}_{O2}$ found at minute nine, the difference found was probably again a result of the small subject number.

Figure 4 shows the rate of increase in heart rate of the eleven subjects in the two protocols. In protocol one, there was a linear increase until about the twelth minute where it levelled off.

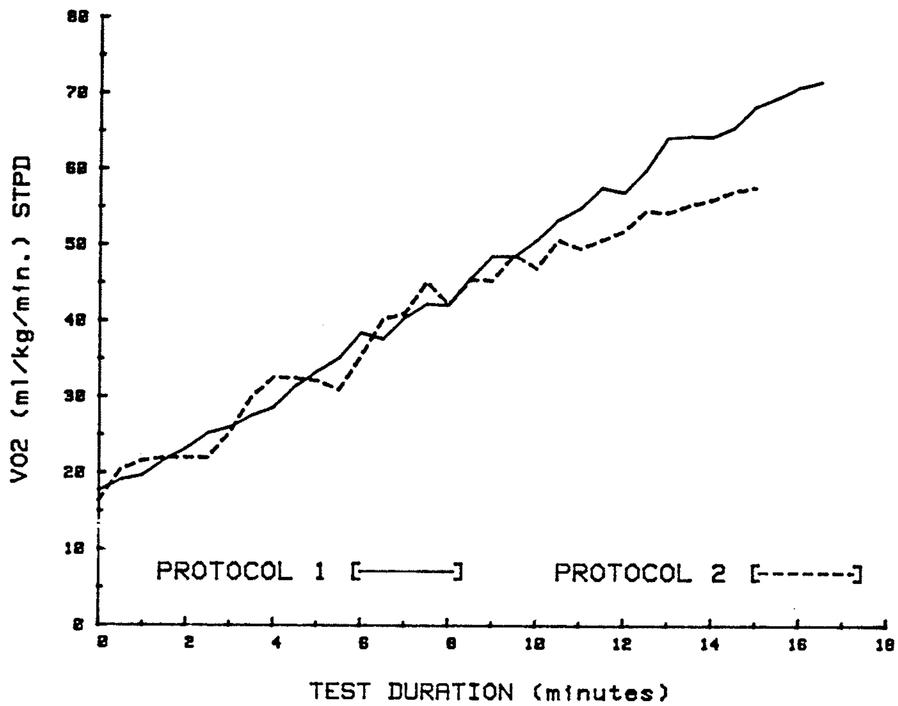


Figure 2
Example of Rate of Increase in Relative Oxygen Uptake in the Two Protocols (Single Subject)

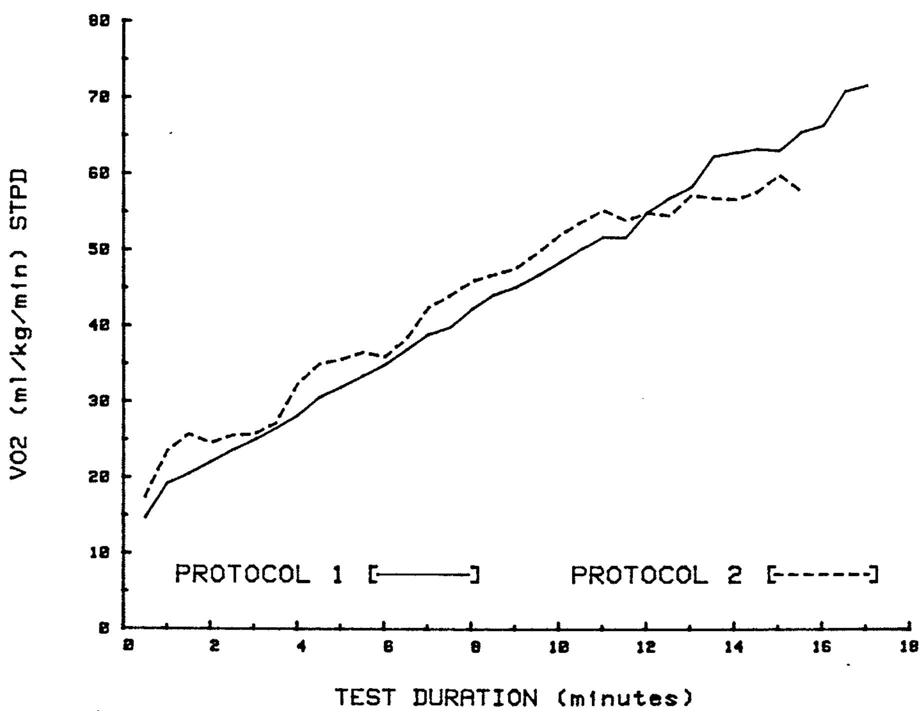


Figure 3
Rate of Increase in Relative Oxygen Uptake in the Two Protocols (N=11)

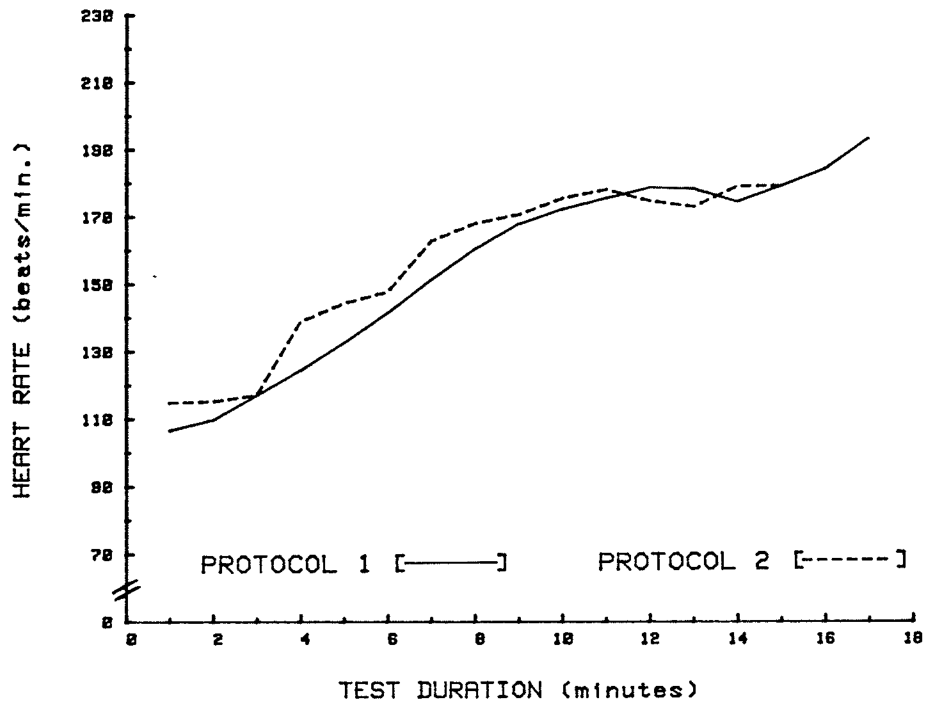


Figure 4
Rate of Increase in Heart Rate in the Two Protocols (N=11)

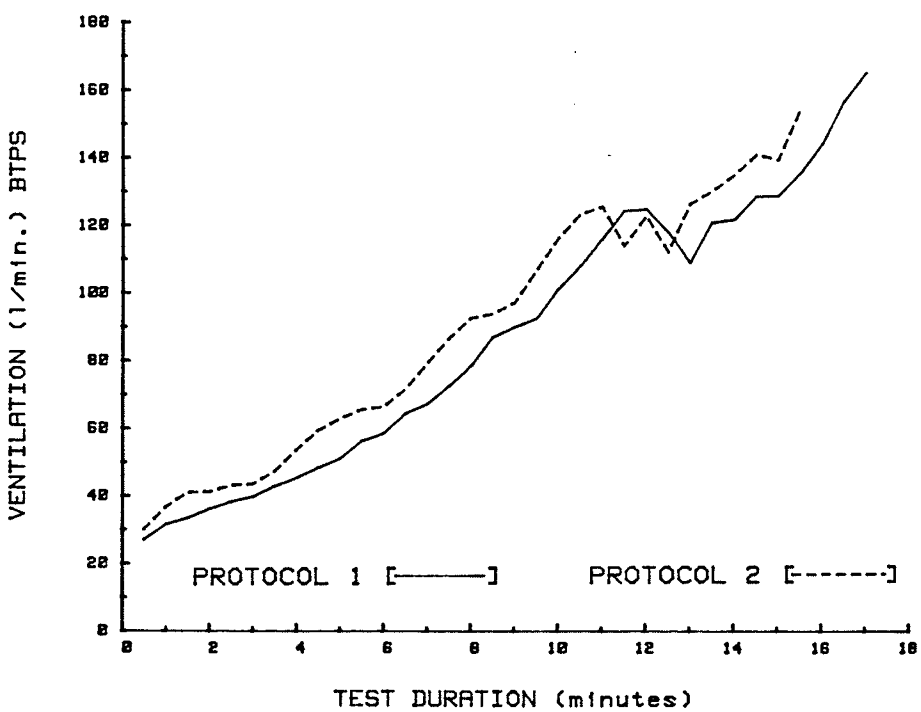


Figure 5
Rate of Increase in Ventilation in the Two Protocols (N=11)

The mean maximum time on protocol one occurred at about twelve and one half minutes. The upward trend at minute fourteen corresponded to the two subjects who had not yet reached maximum. Protocol two showed a stepwise increase in heart rate corresponding to the three minute work loads. This difference in the graph of heart rate (between the two protocols) would be expected.

In protocol two, the subjects' heart rate had adjusted to the lower work loads. When the work load was subsequently increased, there was a rapid increase in heart rate until adjustment to the new work load occurred. Conversely in protocol one, the magnitude of the work load increase (1/3 of the work load of protocol 2) plus the fact that the work load was increased at one minute intervals, meant that the adjustments were not large enough to be detected individually.

Ventilation and Carbon Dioxide Production

Submaximal $\dot{V}_E$ and $\dot{V}_{CO_2}$ measurements were consistently different between the two protocols. Except for minute twelve, protocol two was significantly greater. This would lead to the conclusion that the two protocols resulted in different breathing patterns. The larger increments in protocol two could possibly account for the greater production of CO_2 at equal work loads. This may be due to the larger anaerobic portion of work at the beginning of each work load in this protocol.

Figures 5 (p. 36) and 6 show the rate of increase in $\dot{V}_E$

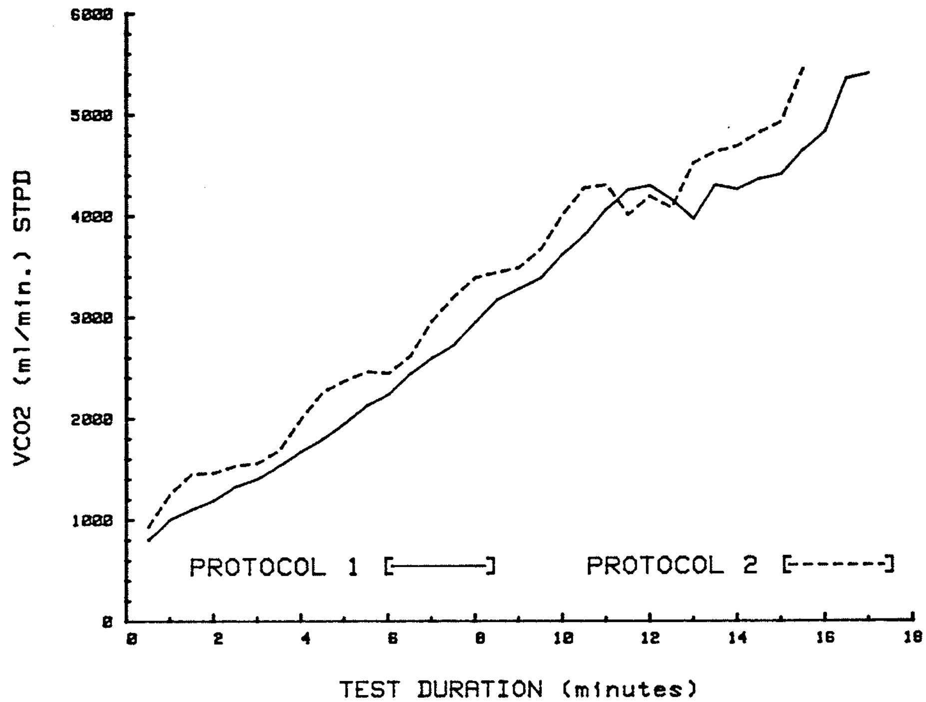


Figure 6
Rate of Increase in Carbon Dioxide Production in the Two Protocols (N=11)

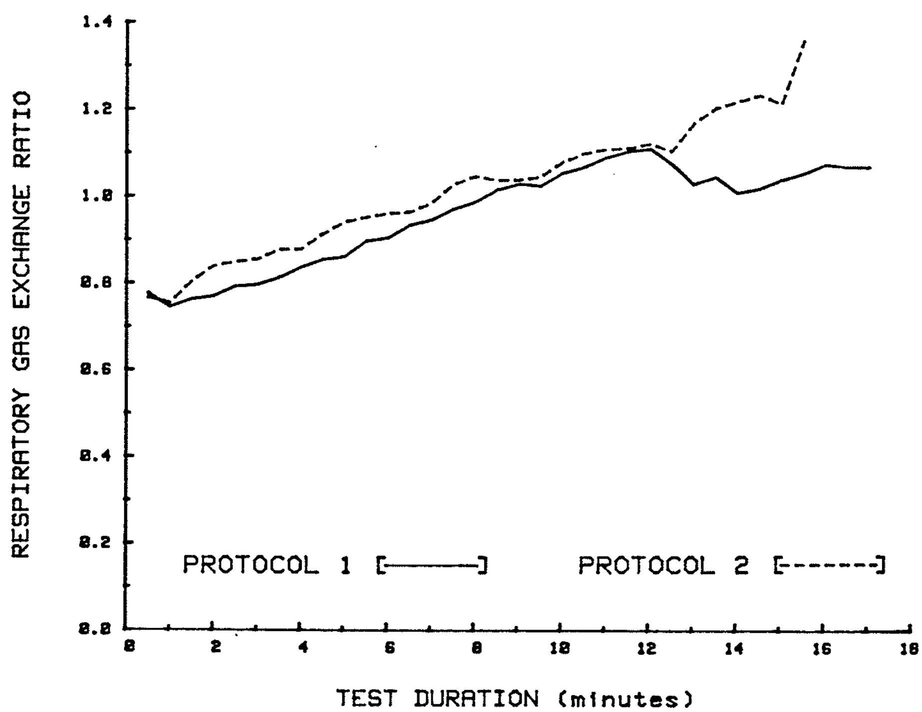


Figure 7
Rate of Increase in Respiratory Gas Exchange Ratio in the Two Protocols (N=11)

and $\dot{V}_{CO_2}$ of the eleven subjects in the two protocols. Again protocol one showed a linear increase while protocol two had a step-like increase until minute ten to thirteen where most of the subjects stopped. The increase after the plateau was due to the two subjects who continued for a longer period of time.

Respiratory Gas Exchange Ratio

R was significantly greater in protocol two at minute three and six ($p<0.01$). As stated by Aström & Jonsson (1976), the first few minutes in protocol one can be used as an additional warm-up. In protocol two, the higher R values could reflect a longer period of time in adjustment to the actual testing procedure. As the work loads increased towards maximum (about minute six), there were no significant differences found. The subjects were now working at intensities which would override any changes in R due to anxiety.

Figure 7 (p. 38) shows the rate of increase in R of the eleven subjects in the two protocols. Both protocols increased in the same fashion (as other variables) until minute twelve. At this point, many subjects completed the test, thus causing a change in trend.

Anaerobic Threshold

The anaerobic threshold for protocol one and two estimated using the various respiratory variables was 74.97 $\pm$ 7.02% and 75.05 $\pm$ 9.94% of $\dot{V}_{O_2}$ max, respectively. In $\dot{V}_{O_2}$ values, this would be 2.96 $\pm$ 0.40 l/min or 43.27 $\pm$ 5.82 ml/kg/min for protocol one and 2.93 ± 0.56 l/min or 41.34 ± 6.37 ml/kg/min for protocol two. Recent research has shown that the anaerobic threshold is higher after an endurance program (Ready, 1980; Davis et al., 1979), but more research is needed in this area. The range obtained for the anaerobic threshold in this study (65.8%-88.8% for protocol 1, 59.1%-89.2% for protocol 2) corresponds well to the results of other studies using trained individuals (Prietto et al., 1981; Rusko et al., 1980; Costill, 1970). The comparison of the training programs of each individual subject will not be discussed here as it is beyond the scope of this study.

The anaerobic threshold was not significantly different between the two protocols ($t = -0.026$; $t_{.05} = 1.96$). Both protocols detected the anaerobic threshold at the same point using the respiratory variables.

An example of the detection of the anaerobic threshold of two different subjects, one on protocol one and the other on protocol two is given in Figures 8 and 9. The anaerobic threshold could easily be detected using the two criteria, $\dot{V}_E/\dot{V}_{O_2}$ and F_{EO_2}, because of the increase from a generally flat slope to a much steeper slope. The same point was more difficult to detect using $\dot{V}_E$ and R because both increased fairly linearly throughout the test, and anaerobic threshold is detected by a change in slope. This was also found in other studies (Prietto et al., 1981; Davis et al., 1979).

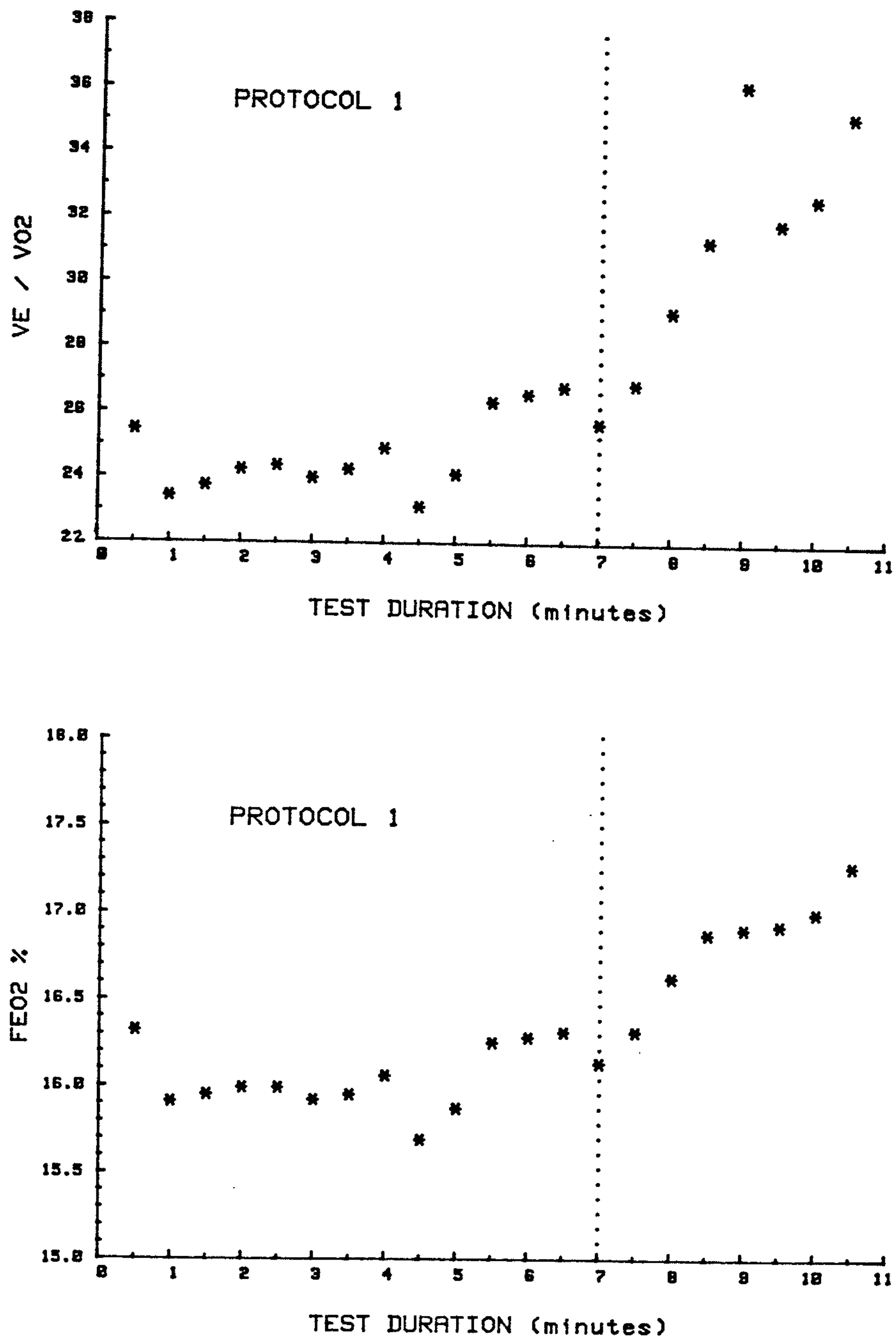
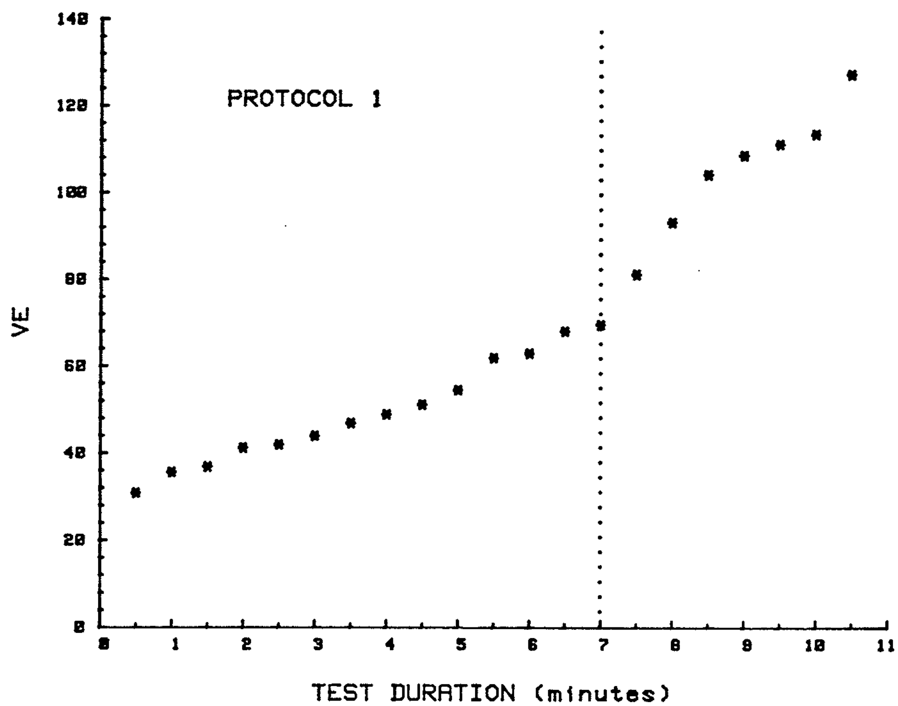


Figure 8

Example of the Graphical Determination of Anaerobic Threshold in Protocol One (Single Subject)



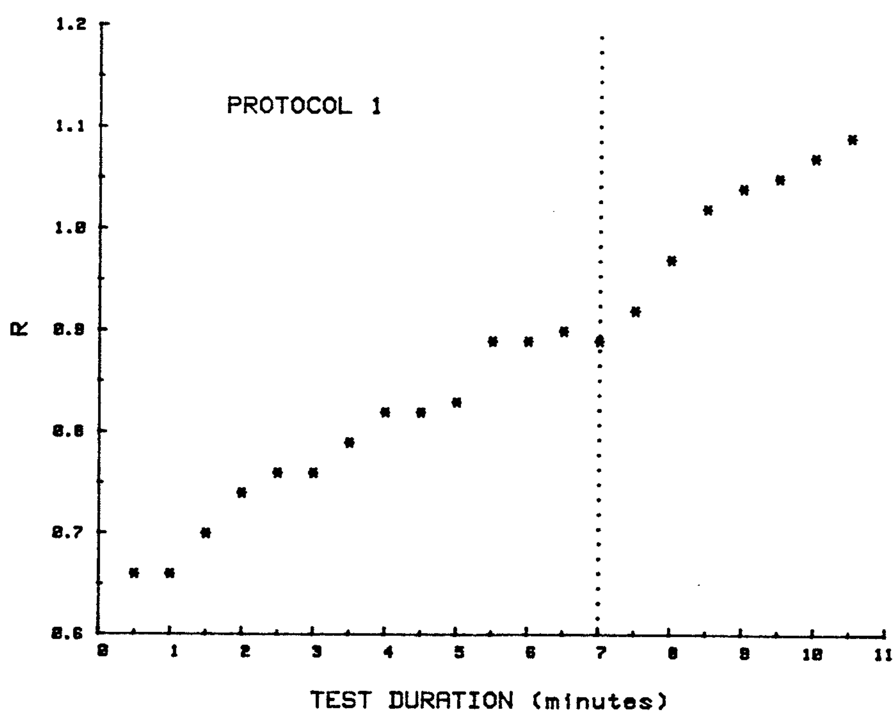


Figure 8 (continued)

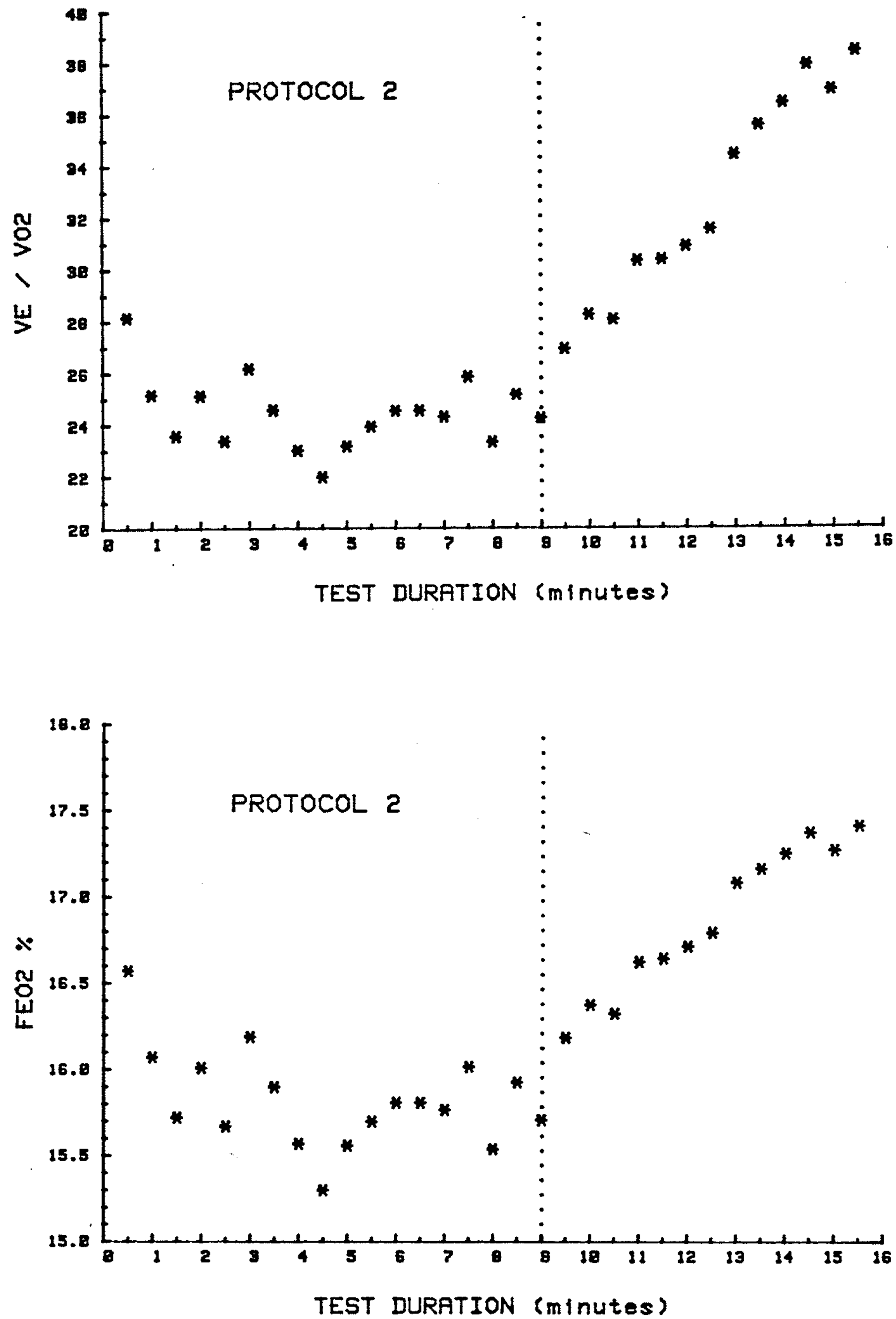
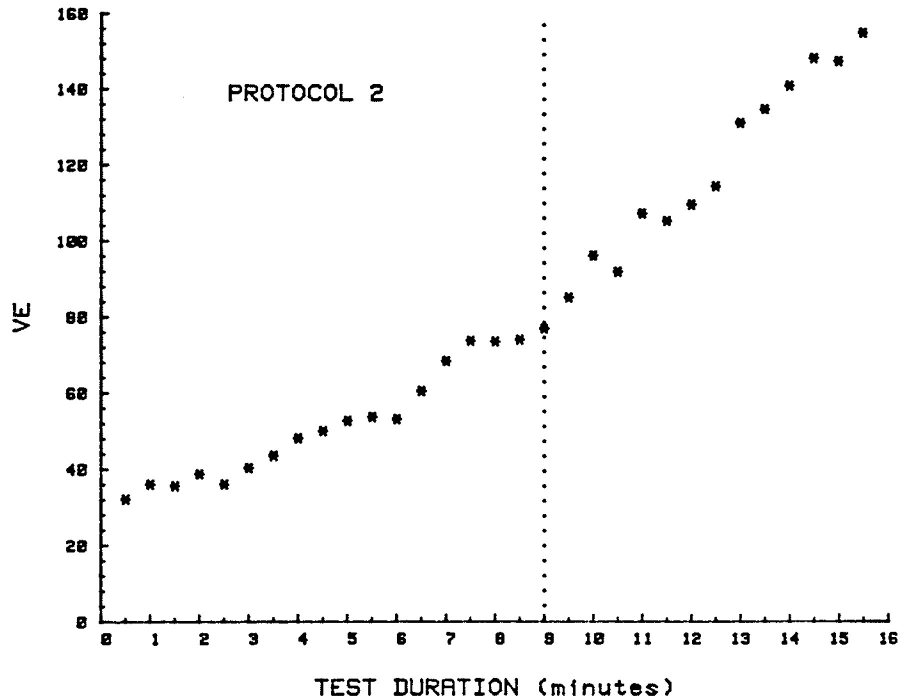


Figure 9

Example of the Graphical Determination of Anaerobic Threshold in Protocol Two (Single Subject)



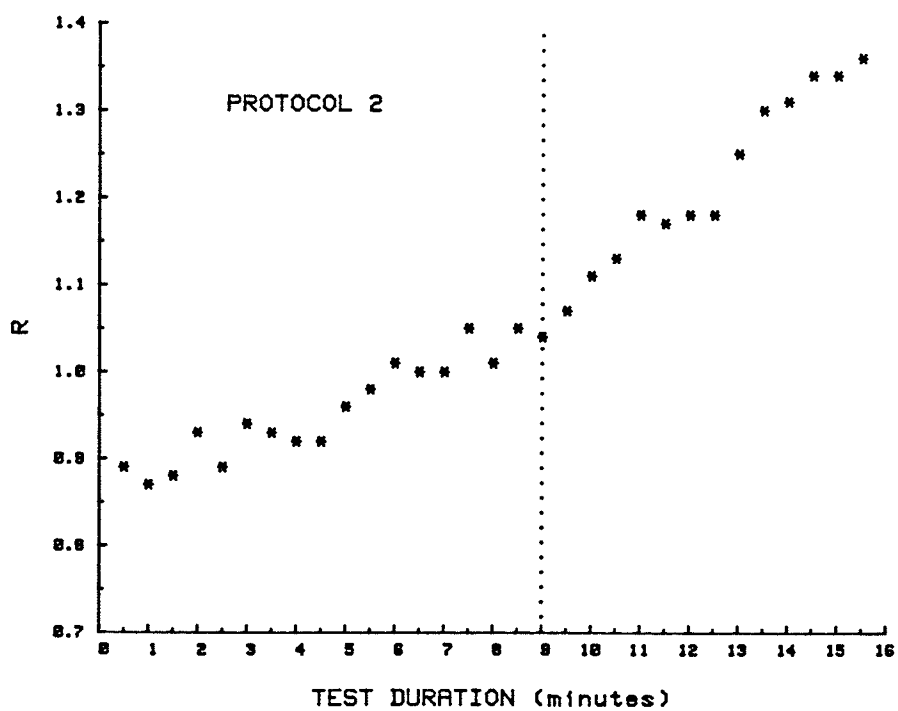


Figure 9 (continued)

Chapter 5

SUMMARY AND CONCLUSIONS

The following conclusions prove justified on the basis of the previously mentioned limitations:

1) The continuous protocol (1 minute stages) and the progressive steady-state protocol (3 minute stages) resulted in the same maximal physiological measurements.
2) The continuous protocol was significantly longer than the progressive steady-state protocol.
3) Equivalent submaximal work loads of the two protocols provided the same measurements in $\dot{V}_{O_2}$ and heart rate but significant differences were found in $\dot{V}_E$, $\dot{V}_{CO_2}$ and R.
4) The anaerobic threshold was detected at the same level in both protocols using respiratory variables.

Recommendations

The following recommendations may be found useful for further research in this area:

1) A larger sample size would help eliminate much of the biological or subject variation.
2) A group of untrained subjects should be included to see if the same results are obtained from the two test protocols.

3) A standardized procedure for detecting the anaerobic threshold on a treadmill test protocol should be developed.

BIBLIOGRAPHY

Astrand, P.-O., & Rodahl, K. Textbook of Work Physiology. Toronto: McGraw-Hill Company, 1977.

Aström, H., & Jonsson, B. Design of exercise test, with special reference to heart patients. British Heart Journal, 1976, 38, 289-296.

Balke, B., & Ware, R.W. An experimental study of 'physical fitness' of Air Force personnel. U.S. Armed Forces Medical Journal, 1959, 10 (6), 675-688.

Barry, A.J., Webster, G.W., & Daly, J.W. Validity and reliability of a multistage exercise test for older men and women. Journal of Gerontology, 1969, 24, 284-291.

Bruce, R.A., Blackman, J.R., Jones, J.W., & Strait, G. Exercise testing in adult normal subjects and cardiac patients. Pediatrics, 1963, October Supplement, 742-756.

Bruce, R.A., Kusumi, F., & Hosmer, D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. American Heart Journal, 1975, 85 (4), 546-562.

Costill, D.L. Metabolic responses during distance running. Journal of Applied Physiology, 1970, 28, 251-255.

Cotes, J.E., Allsopp, D., & Sardi, F. Human cardiopulmonary responses to exercise: comparisons between arm and leg exercise, and between subjects differing in body weight. Quarterly Journal of Experimental Physiology, 1969, 54, 211-222.

Davis, J., Frank, M., Whipp, B., & Wasserman, K. Anaerobic threshold alterations caused by endurance training in middle-aged men. Journal of Applied Physiology, 1979, 46, 1039-1046.

Davis, J.A., Vodak, P., Wilmore, J.H., Vodak, J., & Kurtz, P. Anaerobic threshold and maximal aerobic power for three modes of exercise. Journal of Applied Physiology, 1976, 41 (4), 544-549.

Ellestad, M.H., Blomqvist, C.G., & Naughton, J.P. Standards for adult exercise testing laboratories. Circulation, 1979, 59, 421A-430A.

Falls, H.B., & Humphrey, L.D. A comparison of methods for eliciting maximum oxygen uptake from college women during treadmill walking. Medicine and Science in Sports, 1973, 5 (4), 239-241.

Fardy, P.S., & Hellerstein, H.K. A comparison of continuous and intermittent progressive multistage exercise testing. Medicine and Science in Sports, 1978, 10 (1), 7-12.

Fernandez, E.A., Mohler, J.G., & Butler, J.P. Comparison of oxygen consumption measured at steady state and progressive rates of work. Journal of Applied Physiology, 1974, 37 (6), 982-987.

Fortuin, N.J., & Weiss, J.L. Exercise stress testing. Circulation, 1977, 56, 699-713.

Froelicher, V.F., Brammell, H., Davis, G., Noguera, I., Stewart, A., & Lancaster, M.C. A comparison of the reproducibility and physiologic response to three maximal treadmill exercise protocols. Chest, 1974, 65 (5), 512-517.

Froelicher, V.F., & Lancaster, M.C. The prediction of maximal oxygen consumption from a continuous exercise treadmill protocol. American Heart Journal, 1974, 87 (4), 445-450.

Froelicher, V.F., Thompson, A.J., Noguera, I., Davis, G., Stewart, A., & Triebwasser, J.H. Prediction of maximal oxygen consumption. Chest, 1975, 68 (3), 331-336.

Hagberg, J.M., Hickson, R.C., Ehsani, A.A., & Holloszy, J.O. Faster adjustment to and recovery from submaximal exercise in the trained state. Journal of Applied Physiology, 1980, 48 (2), 218-224.

Hermansen, L., & Saltin, B. Oxygen uptake during maximal treadmill and bicycle exercise. Journal of Applied Physiology, 1969, 26 (1), 31-37.

Hickson, R.C., Bomze, H.A., & Holloszy, J.O. Faster adjustment of O_2 uptake to the energy requirement of exercise in the trained state. Journal of Applied Physiology, 1978, 44 (6), 877-881.

Hughson, R.L., Kowalchuk, J.M., Prime, W.M., & Green, H.J. Open-circuit gas exchange analysis in the non-steady-state. Canadian Journal of Applied Sport Sciences, 1980, 5 (1), 15-18.

MacDougall, J.D. The anaerobic threshold: Its significance for the endurance athlete. Canadian Journal of Applied Sport Sciences, 1977, 2, 137-140.

McKay, G.A., & Bannister, E.W. A comparison of maximal oxygen uptake determination by bicycle ergometry at various pedaling frequencies and by treadmill running at various speeds. European Journal of Applied Physiology and Occupational Physiology, 1976, 35, 191-196.

Mellerowicz, H., & Smodlaka, V.N. Ergometry. Baltimore: Urban & Schwarzenberg, 1981.

Mitchell, J.H., & Blomqvist, G. Maximal oxygen uptake. The New England Journal of Medicine, 1971, 284, 1018-1022.

Mitchell, J.H., Sproule, B.J., & Chapman, C.B. The physiological meaning of the maximal oxygen intake test. Journal of Clinical Investigation, 1958, 37, 538-547.

Miyamura, M., Kitamura, K., Yamada, A., & Matsui, H. Cardiorespiratory responses to maximal treadmill and bicycle exercise in trained and untrained subjects. Journal of Sports Medicine, 1978, 18, 25-32.

Montoye, H.J., Guber, S., Cunningham, D.A., & Dinka, S. Age and acquisition of a 'steady-state' during continuous graded treadmill exercise. Physiologist, 1970, 13, 263. (Abstract)

Naimark, A., Wasserman, K., & McIlroy, M.B. Continuous measurement of ventilatory exchange ratio during exercise. Journal of Applied Physiology, 1964, 19 (4), 644-652.

Pollock, M.L., Bohannon, R.L., Cooper, K.H., Ayres, J.J., Ward, A., White, S.R., & Linnerud, A.C. A comparative analysis of four protocols for maximal treadmill stress testing. American Heart Journal, 1976, 92 (1), 39-46.

Prietto, C.A., Caiozzo, V.J., Ellis, J.F., Davis, J.A., & McMaster, W.C. Anaerobic thresholds in elite middle and long distance runners. The American Medical Joggers Association Newsletter, 1981, October, 12-15.

Ready, A.E. Adaptations to endurance training and detraining: changes in systemic and local muscle parameters and in serum lipids and lipoproteins. Doctoral dissertation, University of Alberta, Fall 1980.

Rusko, H., Rahkila, P., & Karvinen, E. Anaerobic threshold, skeletal muscle enzymes and fiber composition in young female cross-country skiers. Acta Physiologica Scandinavica, 1980, 108, 263-268.

Shephard, R.J. Endurance Fitness. Toronto: University of Toronto Press, 1977.

Shephard, R.J., Allen, C., Benade, A.J.S., Davies, C.T.M., dePrampero, P.E., Hedman, R., Merriman, J.E., Myhre, K., & Simmons, R. The maximum O_2 intake - an international reference standard of cardio-respiratory fitness. Bulletin, World Health Organization, 1968, 38, 757-764.

Skinner, J.S., & McLellan, T.H. The transition from aerobic to anaerobic metabolism. Research Quarterly for Exercise and Sport, 1980, 51, 234-248.

Stainsby, W.N., & Barclay, J.K. Exercise metabolism: O_2 deficit, steady level O_2 uptake and O_2 uptake for recovery. Medicine and Science in Sports, 1970, 2 (4), 177-181.

Stamford, B.A. Maximal oxygen uptake during treadmill walking and running at various speeds. Journal of Applied Physiology, 1975, 39 (3), 386-389.

Sutton, J.R. Exercise responses in post myocardial infarction patients. Medicine and Science in Sports, 1979, 11 (4), 366-367.

Taylor, H.L., Buskirk, E., & Henschel, A. Maximal oxygen intake as an objective measure of cardio-respiratory performance. Journal of Appied Physiology, 1955, 8, 73-80.

Taylor, H.L., Wang, Y., Rowell, L., & Blomqvist, G. The standardization and interpretation of submaximal and maximal tests of working capacity. Pediatrics, 1963, October Supplement, 703-722.

Wasserman, K., & McIlroy, M.B. Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. The American Journal of Cardiology, 1964, 14, 844-852.

Wasserman, K., Van Kessel, A.L., & Burton, C.G. Interaction of physiological mechanisms during exercise. Journal of Applied Physiology, 1967, 22 (1), 71-85.

Wasserman, K., Whipp, B.J., Koyal, S.N., & Beaver, W.L. Anaerobic threshold and respiratory gas exchange during exercise. Journal of Applied Physiology, 1973, 35 (2), 236-243.

Wells, C.L., & Haan, A.L. Anaerobic threshold in male and female marathon runners. Abstracts: Research Papers 1981 AAHPERD Convention, 1981, 84.

Weltman, A., & Katch, V. Min-by-min respiratory exchange and oxygen uptake kinetics during steady-state exercise in subjects of high and low max $\dot{V}_{O2}$. The Research Quarterly, 1976, 47 (3), 490-498.

Weltman, A., Katch, V., Sady, S., & Freedson, P. Onset of metabolic acidosis (anaerobic threshold) as a criterion measure of submaximum fitness. The Research Quarterly, 1978, 49 (2), 218-227.

Wolthius, R.A., Froelicher, V.F., Fischer, J., Noguera,I., Davis, G., Stewart, A.J., & Triebwasser, J.H. New practical treadmill protocol for clinical use. The American Journal of Cardiology, 1977, 39, 697-700.

APPENDICES

APPENDIX A

DOCUMENTS FOR RESEARCH INVOLVING HUMAN SUBJECTS

PAR-Q

In order to ensure that the exercise test will not have any detrimental effects on yourself, it is mandatory that you read each point below carefully before answering YES or NO.

Should you have any questions please ASK.

YES or NO

1. ________ Have you had any pains, pressure or discomfort in the middle of your chest when you exert yourself?
2. ________ Have you ever been told you have heart trouble such as rheumatic fever, heart murmur, angina pectoris?
3. ________ Have you ever taken any heart drugs (digitalis, quinidine, nitroglycerine)?
4. ________ Do you have trouble with palpitations?
5. ________ Does one flight of stairs make you severely breathless?
6. ________ Have you had previous heart trouble or high blood pressure?
7. ________ Are you 25 pounds overweight or do you smoke over a package of cigarettes a day?

8. ________ Do you have blood relatives who have a strong tendency towards heart attacks?

9. ________ Do you have diabetes?

10. ________ Do you have limb, joint, chest (respiratory) or any other chronic disorders that might worsen with exercise?

11. ________ Are you over 50 years of age?

If you have answered YES to any of these questions you will be advised to have medical clearance by a physician.

Name: ________________________

Date: ________________________

INFORMED CONSENT FOR TREADMILL TEST TO EXHAUSTION

1. EXPLANATION OF THE TESTS

You will perform an exhaustive running test of aerobic capacity on a treadmill. We expect your heart rate and oxygen consumption to reach maximum levels for your age and fitness level. You can anticipate being quite fatigued upon completion.

2. RISKS AND DISCOMFORTS

There exists the possibility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorders of heart beat, and in very rare instances, heart attack. Every effort will be made to minimize them by preliminary screening, medical examination and by close observation during the testing. Trained personnel will conduct the testing and emergency procedures have been carefully outlined to deal with unusual situations which may arise.

3. BENEFITS TO BE EXPECTED

The results obtained will provide a precise indication of your aerobic capacity as measured by oxygen consumption and performance time. Subsequent testing will provide you with quantitative data on the effectiveness your training program is in improving your aerobic fitness level and your performance.

4. INQUIRIES

We invite your questions about the procedures to be used in the tests. If you have any doubts as to what is expected of you, please ask us for further explanation.

5. FREEDOM OF CONSENT

Your agreement to take this test is voluntary. You are free to deny consent if you so desire.

I have read this form and I understand the test procedures that I will perform, and I consent to participate in this test.

______________________________ ______________________________

Date Signature of Participant

____

Signature of Witness

Dates of Tests

Name ______________________ 1. ______________________

2. ______________________

3. ______________________

INFORMATION SHEET

- Avoid smoking for at least one hour before the test.
- No exercise routines the day of the test.
- DO NOT eat one hour before the test. A light meal before this is permissible if you avoid butter, cream, coffee, tea, or alcohol.
- Bring a complete list of medications currently being taken.
- Take your regular medicines (if any) before the scheduled test.
- Get a good night's sleep before your test.
- Bring a pair of slacks or shorts with you for your exercise test. Also bring running shoes or comfortable walking shoes.
- Plan to spend approximately one hour at the testing center.
- Locker and shower facilities are available for your convenience.

APPENDIX B

PROTOCOLS

TREADMILL PROTOCOLS

PROTOCOL 1			PROTOCOL 2	
Elevation	Speed	MINUTES	Elevation	Speed
0%	2.4 km.		0%	2.4 km.
0%	3.2 km.		0%	3.2 km.
2%	5.4 km.	1	6%	5.4 km.
4%	5.4 km.	2	6%	5.4 km.
6%	5.4 km.	3	6%	5.4 km.
8%	5.4 km.	4	12%	5.4 km.
10%	5.4 km.	5	12%	5.4 km.
12%	5.4 km.	6	12%	5.4 km.
14%	5.4 km.	7	18%	5.4 km.
16%	5.4 km.	8	18%	5.4 km.
18%	5.4 km.	9	18%	5.4 km.
20%	5.4 km.	10	24%	5.4 km.
22%	5.4 km.	11	24%	5.4 km.
24%	5.4 km.	12	24%	5.4 km.
24%	5.7 km.	13	24%	6.3 km.
24%	6.0 km.	14	24%	6.3 km.
24%	6.3 km.	15	24%	6.3 km.
24%	6.6 km.	16	24%	7.2 km.
24%	6.9 km.	17	24%	7.2 km.
24%	7.2 km.	18	24%	7.2 km.

APPENDIX C

VARIABLES MEASURED AND CALCULATED BY THE BECKMAN METABOLIC MEASUREMENT CART

VARIABLES MEASURED AND CALCULATED BY THE BECKMAN METABOLIC MEASUREMENT CART

The "Exercise Program" was used in the Beckman Metabolic Measurement Cart (MMC). The technician inputed the resting oxygen uptake as well as the body weight. Every 30 seconds, the following measurements and calculations were made:

MEASUREMENTS

Fraction of expired carbon dioxide (F_ECO_2)

Fraction of expired oxygen (F_EO_2)

Expired gas temperature (°C)

Barometric pressure (Pb-mmHg)

Expiratory minute volume ($\dot{V}_E$-liters, BTPS)

Number of breaths (F)

Duration of measurement interval (seconds)

CALCULATIONS

1) Oxygen uptake

$$\dot{V}_{O_2}\ (STPD) = \left[\left(\frac{1 - F_EO_2 - F_ECO_2}{1 - F_{IO_2}} \times F_{IO_2}\right) - F_EO_2\right] \times \dot{V}_E\ (STPD) \times 10^3$$

2) Oxygen uptake corrected for body weight, ml/min/kg (STPD)

$$\frac{\dot{V}_{O_2}}{Wt\ (Kg)}$$

3) Volume exhaled (l/min)

$$\dot{V}_E\ (STPD) = \dot{V}_E\ (BTPS) \times \frac{P_B - 47}{863}$$

4) Respiratory gas exchange ratio

$$R = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}}$$

5) Carbon dioxide production, ml/min (STPD)

$$\dot{V}_{CO_2} = [F_ECO_2 - .0003] \times \dot{V}_E \text{ (STPD)} \times 10^3$$

6) Mets (multiple of resting oxygen consumption)

$$\text{METS} = \frac{\dot{V}_{O_2} \text{ measured}}{\dot{V}_{O_2} \text{ resting}}$$

7) T_{O2} (true oxygen, ml (O_2)/100 ml)

$$T_{O2} = \frac{\dot{V}_{O2} \text{ (ml/min)}}{\dot{V}_E \text{ (STPD) (1/min)}} \times 10^{-1}$$

8) $\dot{V}_E$ (ventilatory equivalent, L/100 ml)

$$\dot{V}_E = \frac{\dot{V}_E \text{ (STPD)}}{\dot{V}_{O_2}} \times 10^2$$

APPENDIX D

STATISTICAL SIGNIFICANCE FOR MAXIMAL AND SUBMAXIMAL TREADMILL STRESS TEST VALUES: INTERPROTOCOL COMPARISONS (STUDENT'S PAIRED T-TEST)

Table 7

Statistical Significance for Maximal Treadmill Stress Test Values: Interprotocol Comparisons (Student's Paired T-Test)

	Mean	Standard Deviation	Standard Error	T-Score
Test Duration (seconds)	.60	26.83	8.09	-7.42**
$\dot{V}_{O_2}$ max (ml/kg/min)	-1.27	4.92	1.48	- .86
$\dot{V}_{O_2}$ max (ml/min)	-82.73	354.71	106.95	- .77
Heart Rate (beats/min)	-1.36	4.57	1.38	- .99
$\dot{V}_E$ max (liters/min-BTPS)	-2.49	14.12	4.26	- .58
$\dot{V}_{CO_2}$ max (ml/min)	-56.36	209.01	63.02	- .89
R	.01	.11	.03	.30

* $p < 0.05$ $t_{.05} = 1.96$

** $p < 0.01$ $t_{.01} = 2.576$

Table 8

Statistical Significance for Submaximal Treadmill Stress Test Values: Interprotocol Comparisons (Student's Paired T-Test)

3 Minutes (6%-5.4 km.)	Mean	Standard Deviation	Standard Error	T-Score
$\dot{V}_{O_2}$ (ml/kg/min)	.80	2.18	.66	-1.22
$\dot{V}_{O_2}$ (ml/min)	-58.18	150.39	45.34	-1.28
Heart Rate (beats/min)	-9.09	6.88	2.07	- .04
$\dot{V}_E$ (liters/min-BTPS)	-3.87	3.53	1.06	-3.64**
$\dot{V}_{CO_2}$ (ml/min)	-155.45	102.89	31.02	-5.01**
R	-5.82	6.57	1.98	-2.94**
6 Minutes (12%-5.4 km.)				
$\dot{V}_{O_2}$ (ml/kg/min)	-1.03	2.23	.67	-1.53
$\dot{V}_{O_2}$ (ml/min)	-68.18	154.13	46.47	-1.47
Heart Rate (beats/min)	-6.27	8.59	2.59	-2.42*
$\dot{V}_E$ (liters/min-BTPS)	-7.93	5.32	1.60	-4.94**
$\dot{V}_{CO_2}$ (ml/min)	-210.91	169.97	51.25	-4.12**
R	-5.64	7.14	2.15	-2.62**
9 Minutes (18%-5.4 km.)				
$\dot{V}_{O_2}$ (ml/kg/min)	-2.36	2.76	.87	-2.70**
$\dot{V}_{O_2}$ (ml/min)	-170.00	209.66	66.30	-2.56*
Heart Rate (beats/min)	-3.50	5.82	1.84	-1.90
$\dot{V}_E$ (liters/min-BTPS)	-9.93	8.28	2.62	-3.79**
$\dot{V}_{CO_2}$ (ml/min)	-257.00	187.26	59.22	-4.34**
R	- .03	7.79	2.46	-1.10

Table 8 (continued)

12 Minutes (24%-5.4 km.)				
$\dot{V}_{O_2}$ (ml/kg/min)	-.82	5.31	2.65	- .31
$\dot{V}_{O_2}$ (ml/min)	-57.50	401.61	200.81	- .29
Heart Rate (beats/min)	-.50	4.73	2.36	-.21
$\dot{V}_E$ (liters/min-BTPS)	-14.52	9.23	4.62	-3.15**
$\dot{V}_{CO_2}$ (ml/min)	-315.00	304.25	152.12	-2.07*
R	-.07	.13	6.67	-1.05
15 Minutes (24%-6.3 km.)				
$\dot{V}_{O_2}$ (ml/kg/min)	3.20	7.21	5.10	.63
$\dot{V}_{O_2}$ (ml/min)	210.00	593.97	420.00	.50
Heart Rate (beats/min)	0.00	0.00	0.00	0.00
$\dot{V}_E$ (liters/min-BTPS)	-10.60	2.12	1.50	-7.07**
$\dot{V}_{CO_2}$ (ml/min)	-515.00	275.77	195.00	-2.64**
R	-.18	.22	.16	-1.13

* $p < 0.05$ $t_{.05} = 1.96$

** $p < 0.01$ $t_{.01} = 2.576$