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A Comparison Of Four Protocols For Maximal Treadmill Graded Exercise Testing In Endurance Athletes

By

Eric E. Vinje

B.S., Furman University, 1986

Presented in partial fulfillment of the requirements

for the degree of

Master of Science

UNIVERSITY OF MONTANA

1988

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Chairman, Board of Examiners

Dean, Graduate School

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Vinje, Eric E., M.S., November 1988 Physical Education

A Comparison Of Four Protocols For Maximal Treadmill Graded Exercise Testing In Endurance Athletes (65 pp.)

Director: Dr. Michael F. Zupan

This study attempted to determine whether standard treadmill protocols (protocols set up for the non-athlete) were appropriate for measuring maximal values in well-trained endurance athletes. Furthermore, this study compared a horizontal protocol to three inclined protocols to try and determine which treadmill graded exercise test elicits higher max $\dot{V}O_2$ values. Twenty well-trained male endurance athletes served as subjects. Each subject was required to perform 4 randomly assigned maximal oxygen uptake treadmill tests. These treadmill tests consisted of two standard protocols (Bruce, Astrand) and two more intense protocols (Montana Vertical, North Dakota Horizontal). All oxygen consumption measurements were obtained every half minute using a Sensormedics Metabolic Measurement cart. Heart rate measurements were recorded during each subjects initial test with a conventional apparatus (Burdick) using a 3-electrode lead configuration. Heart rate measurements were recorded every half minute with a CIC heart rate monitor for each additional test.

Data analysis was carried out on a VAC computer utilizing the Statistical Programs for the Social Sciences (SPSS). SPSS was used for generation of the descriptive statistics. The basic statistical analysis used to compare tests was an analysis of variance for repeated measures(ANOVA). Significance was set at $\underline{p} \leq .05$. The Scheff'e a posteriori procedure was then performed to determine how the means differ. Significance for this procedure was set at $\underline{p} \leq .10$.

Within the limits of the methods used this study concluded: (1) That the two standard treadmill protocols are capable of measuring valid max $\dot{V}O_2$ values in well-trained endurance runners. Further, the longer test duration of these protocols did not appear to produce muscular fatigue factors great enough to limit the athletes cardiovascular capacity; (2) When the vertical protocols (Bruce, Astrand, Vertical) were compared to the Horizontal protocol, a significant difference was found to exist between the Bruce and Horizontal tests and max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$); and (3) When factors such as test duration, subject comfort, and ease of administration were considered, this author found that the Astrand and Vertical protocols were actually more appropriate for testing the endurance athlete than the Bruce protocol.

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The author would like to express his sincere gratitude to Dr. Michael F. Zupan, who, as graduate advisor devoted his time and effort in the writing of this thesis. Further appreciation goes to the other members of my committee, Dr. Tom Whiddon and Dr. Ian Lange for their encouragement, patience, and helpful suggestions.

A very special thanks is indeed necessary to those who served as subjects and laboratory assistants in this study. Without their help and dedication this study would have never been accomplished.

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CHAPTER I

INTRODUCTION

Graded exercise treadmill testing is generally considered the ideal instrument for determining maximal oxygen consumption (max $\dot{V}O_2$). Max $\dot{V}O_2$ may be the best index of cardiovascular fitness, since the oxygen transport system is considered to be the major limiting factor for exercise (Astrand & Rodhal, 1977). Because of this, it is very important that reliable measurements be obtained, this is especially true when a) comparing individuals or groups; b) when applying the results of these tests to designing individualized conditioning programs; and c) when following subjects over a period of time.

At present, several maximal graded exercise treadmill test protocols are in common use across the country, but no one protocol has been considered to be superior at measuring maximal values (Pollock et al., 1978). This is most evident when testing the well-trained endurance athlete. It is speculated that in many cases, the duration of a standard treadmill test (one designed for the non athlete) for this level athlete may become so great that the subject terminates the test due to local muscular

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fatigue rather than the athlete achieving his maximal oxygen consumption.

Numerous treadmill protocols have been developed to elicit maximum values. The majority of these protocols use both increases in speed and grade to achieve maximal levels of performance. The research is controversial as to whether an inclined protocol (Astrand & Saltin, 1981; Hermansen & Saltin, 1969; Molnar, Milesis, & Massey, 1974; Taylor, Buskirk, & Henscel, 1955) or a horizontal protocol (Freund, Allen, & Wilmore, 1986; Kasch, Wallace, & Huttu, 1986; Sucec, 1974; Wilson, Monego, Howard, & Thompson, 1979) will elicit higher max $\dot{V}O_2$ values.

The purpose of this study was to develop a reliable treadmill graded exercise test which allowed for the endurance athlete to meet the limits of his cardiovascular capacity and reliably measure maximal oxygen uptake. Furthermore, this study compared a horizontal protocol and inclined protocol to determine which treadmill graded exercise test elicits higher max $\dot{V}O_2$ values.

A modified horizontal treadmill graded exercise test and a modified inclined treadmill graded exercise test were given to all subjects. Two standard treadmill protocols, the Bruce and Astrand test were further administered to the athletes to help make comparisons concerning max $\dot{V}O_2$ values between protocols.

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Significance of Problem

The primary purpose of this study was to determine whether standard treadmill protocols such as the Bruce protocol (the most widely used of the physician directed maximal exercise tests) and Astrand protocol (widely used in Europe for testing both normal populations and athletes) are appropriate for measuring maximal values in well trained endurance athletes. Because the endurance athlete has a much larger aerobic capacity than a sedentary group, it was felt that the duration of these standard treadmill protocols (Bruce, Astrand) ran on so long that the athlete terminated these tests due to local muscular fatigue rather than reaching his max $\dot{V}O_2$. A sub problem of this study compared a horizontal protocol and inclined protocol to determine which treadmill graded exercise test would elicit higher max $\dot{V}O_2$ values. These max $\dot{V}O_2$ values will help coaches in the evaluation of the physical condition of their athletes and of applying the results of these tests to designing individualized training programs. Furthermore, the findings will give valuable insight into the cardiorespiratory endurance training status of the athlete as he is assessed over time.

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Delimitations

The delimitations of this study include the following:

1) The sample population was delimited to 20 well-trained male endurance athletes, between the ages of 18 and 35 years. All subjects were from the Missoula, Montana area.

2) Each subject ran a total of four separate maximal treadmill test protocols which included:

a) The North Dakota horizontal maximal treadmill test protocol.

b) The Montana vertical maximal treadmill test protocol.

c) The Bruce protocol.

d) The Astrand protocol.

Hypotheses

The following hypotheses were examined at a level of significance of $\underline{p} \le .05$:

1) Endurance athletes will attain significantly greater max $\dot{V}O_2$ values on the North Dakota horizontal maximal treadmill test protocol as compared to the two standard protocols (Bruce, Astrand).

2) Endurance athletes will attain significantly greater max $\dot{V}O_2$ values on the Montana vertical maximal treadmill test protocol as compared to the standard protocols (Bruce, Astrand).

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3) Endurance athletes will attain significantly greater max $\dot{V}O_2$ values on the Montana vertical maximal treadmill test protocol as compared to the North Dakota horizontal maximal treadmill test protocol.

Definitions

Maximal oxygen consumption (max $\dot{V}O_2$) is synonymous with the terms maximal oxygen uptake, maximal oxygen intake, and maximal aerobic power. It is the maximum rate at which an individual can take up and consume oxygen. It is the point at which oxygen consumption fails to rise despite an increased exercise intensity or workload (Brooks, & Fahey, 1985).

Peak oxygen consumption (Peak $\dot{V}O_2$) refers to the highest value of oxygen consumption measured during a maximal exercise stress test (McArdle, Katch, & Katch, 1986).

Well trained endurance athlete is an athlete having a maximum $\dot{V}O_2$ value of more than 51.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (Cooper, 1968).

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CHAPTER II

LITERATURE REVIEW

Maximum oxygen uptake (max $\dot{V}O_2$) when measured properly may be the best index of cardiovascular fitness, since the oxygen transport system is considered to be the major limiting factor(s) (Dacosta, Russo, & Picarro, 1984). In order to assure that both the respiratory and circulatory systems reach a level at which true maximum oxygen uptake is measured, it is essential that the proper ergometric device and test procedure be utilized to extend the subject.

The proper ergometric device must engage large muscle groups in order to load the respiratory and circulatory functions to a maximal extent. For this reason bicycle and treadmill exercises have been the two most commonly used laboratory tests for determining max $\dot{V}O_2$ (Kamon, & Pandolf, 1972), with treadmill graded exercise testing being considered the ideal instrument (Astrand & Saltin, 1981). However, no one treadmill protocol has been considered to be superior at measuring maximal values (Pollock et al., 1978). A test primarily used to evaluate the trained endurance athlete is of little value in hospital settings, and tests designed for cardiac patients are not strenuous

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enough for athletes. An exercise test should contain both an exercise intensity and duration that is great enough to elicit a maximal response of the cardiovascular system if max $\dot{V}O_2$ is to be achieved (Lamb, 1984). Therefore, the exercise test should progress from initial exercise loads which can be accomplished without difficulty to more difficult loads which lead to maximal exercise in a reasonably short time.

Because max $\dot{V}O_2$ has become the single most important indicator of the efficacy of the cardio-respiratory system, it is very important that the above factors be taken into consideration in order to assure that valid measurements be obtained. This is especially true when testing the endurance athlete. Pollock, 1973 demonstrated that max $\dot{V}O_2$ is highly responsive to endurance training, with increases of up to 50% or greater, dependent on frequency, duration, intensity and mode of exercise, and the individuals initial level of fitness. Others including Rumell, Michael, & Berry, (1973) and Saltin & Astrand, (1967) have demonstrated substantial decreases in max $\dot{V}O_2$ with decreased activity, bed rest, and extended periods of weightlessness. Thus, max $\dot{V}O_2$ values provide valuable insight into the cardio-respiratory endurance training status of the athlete as he is assessed longitudinally (Wilmore, 1984).

The highest max $\dot{V}O_2$'s are generally recorded for men and women competing in distance running, swimming,

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bicycling, or cross country skiing. These athletes have almost double the aerobic capacity of a sedentary group (McArdle et al., 1986). Because of this increased aerobic capacity, it was speculated by this researcher that a standard treadmill test (one developed for the non athlete, i.e., the Bruce protocol or Astrand protocol) was not intense enough for the endurance athlete. It was believed that the duration of these standard tests lasted so long that the endurance athlete ended up terminating the test due to local muscular fatigue, rather than reaching his max $\dot{V}O_2$. The Trudeau Foundation also felt that maximal oxygen intake had been attained if work conditions were severe enough to exhaust the subject in less than 5 minutes (Taylor et al., 1955). They stated that in well-motivated subjects such as champion athletes or men who have undertaken intensive physical training that this assumption appears to be justified. Pollock et al. (1978) felt that 7-10 minutes was considered an adequate time period for maximal physiological adjustments to occur. It is believed that the severity and duration of the protocol influence results as they affect anaerobic metabolism, localized fatigue, and temperature regulation (Knowlton, Sawka, & Deutsh, 1977).

The American College of Sports Medicine (ACSM) (1986), further mentions that a maximal exercise test is terminated either by muscular fatigue or when max $\dot{V}O_2$ is achieved and no further increase in heart rate occurs. An exercise test

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that results in local muscular fatigue before the limits of cardiovascular capacity are reached is not appropriate for measuring max $\dot{V}O_2$ (Brooks & Fahey, 1985). McArdle et al. (1986) believe that when the generally accepted criteria for the attainment of maximum oxygen uptake are not met or the test performance appears limited by local factors rather than central circulatory dynamics that peak oxygen consumption (Peak $\dot{V}O_2$) is determined.

McArdle et al., (1986) further demonstrated how different exercise test modes could elicit peak $\dot{V}O_2$ values rather than max $\dot{V}O_2$ values. In various experiments where max $\dot{V}O_2$ was determined on the same subjects during different forms of exercise, swimming was generally about 20% below treadmill values. max $\dot{V}O_2$ during bicycle exercise averaged 11.2% below values on the treadmill. Test specificity and local discomfort were the reasons given for these lower oxygen consumption values.

Another factor, that must be considered when evaluating the endurance athlete for maximal oxygen uptake, is the selection of a work task which allows for optimal use of the specifically trained muscle fibers. The foregoing is important since training of specific muscle groups such as the arms and legs may enhance work performance by facilitating both oxygen transport and utilization at the local muscle level (Pechar et al., 1974). Thus differences in muscle recruitment patterns between exercise modes are probably responsible for the

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interactions between the type of training and the work modality used to determine max $\dot{V}O_2$. Laboratory tests should therefore replicate the movement patterns of training if true max $\dot{V}O_2$ is to be achieved (Withers, Sherman, Miller, & Costill, 1981).

As mentioned earlier no one treadmill protocol has been considered to be superior at measuring maximal values. To date, numerous protocols have been developed in an attempt to elicit these values, and the majority of these protocols use both increases in speed and grade. However, the testing procedure varies from one laboratory to another and the crucial question of whether experimental variation of the physical work condition (i.e., treadmill, in this case) could influence maximal $\dot{V}O_2$ remains. If so, it means that comparison of maximal $\dot{V}O_2$ values elicited under different work conditions can not be compared (Molnar et al., 1974).

The research is controversial as to whether an inclined protocol (Astrand & Saltin, 1981; Hermansen & Saltin, 1969; Molnar et al., 1974; Taylor et al., 1955) or a horizontal protocol (Freund et al., 1986; Kasch et al., 1986; Sucec, 1974; Wilson et al., 1979) will elicit higher max $\dot{V}O_2$ values. Taylor et al. (1955) conducted a study where both a horizontal and a vertical protocol were compared. The horizontal protocol consisted of a 0% grade with increases in speed until max $\dot{V}O_2$ had been reached. The vertical protocol used a constant speed of 7 mph and

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the grade increased by 2.5 until max $\dot{V}O_2$ was achieved. From this study it was found that the max $\dot{V}O_2$ produced by increasing the speed was 189 mL·min^{-1} smaller than that produced by raising the grade. Taylor mentions that it is quite possible that this difference in the apparent max $\dot{V}O_2$ can be accounted for by the use of accessory muscles in grade running which are not employed by running on the level.

The above protocols were further compared by Astrand and Saltin (1981) using three well-trained athletes. Their results were in agreement with Taylor et al. (1955) and demonstrated a 4.5% higher max $\dot{V}O_2$ value for the inclined protocol. They suggest that a larger muscle mass is working in running uphill and therefore should increase the oxygen uptake provided the circulatory system could supply the oxygen.

In a study conducted by Molnar et al. (1974) comparisons were made of maximal oxygen consumption elicited at different treadmill grades. The protocols consisted of running at 8 mph to exhaustion under four conditions: 2.5% grade, 5.0% grade, 7.5% grade, and progressive (e.g., in the progressive condition the run started at 2.5% grade and increased by 2.5% increments without interruption until the run was terminated). The results from this study indicated a directionality of higher max $\dot{V}O_2$ values with increasing treadmill grades. This suggests that greater muscle mass utilized at the

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steeper, more intense grades would have some effect on the level of max $\dot{V}O_2$. Molnar further emphasizes that if peripheral factors cannot fully explain the higher maximal $\dot{V}O_2$ at higher grades, then consideration should be given to the role of the sympathetic (accelerator) nerves in augmenting blood circulation and thereby promoting oxygen transport. It is conceivable that the higher intensity of effort at the higher treadmill grades induces nerve activity which in turn serves to enhance oxygen transport and thus accounts for a higher max $\dot{V}O_2$.

When a horizontal and a vertical maximal treadmill protocol were compared to maximal work done on the bicycle ergometer, the results showed the difference in oxygen uptake between maximal uphill running and maximal work on the bicycle ergometer to be 0.34 $L \cdot min^{-1}$. When oxygen uptake during maximal bicycling (50 RPM) was compared to maximal horizontal running, this difference was reduced to 0.14 $L \cdot min^{-1}$. Hermansen & Saltin, (1969) suggest that muscle mass is probably larger during maximal uphill running.

The above studies have supported the notion that the most valid test situation, particularly in the field of exercise physiology, appears to be uphill treadmill running. These observations suggest that maximal aerobic power could be determined by the muscle mass involved. However, research has shown that increasing the muscle mass engagement by employing simultaneous hand cranking and leg

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cycling did not yield higher max $\dot{V}O_2$ than leg cycling only. This was taken to indicate that "the capacity of the heart is the actual limitation" to maximal aerobic capacity (Kamon & Pandolf, 1972).

Conversely, the general consensus of the research supporting a horizontal protocol suggests that at the high treadmill elevations, many subjects experience severe local discomfort in the lower back and calf muscles. McArdle et al., (1986) believe these local factors limit the achievement of maximal work output. Other research supporting a horizontal protocol suggests that the faster running speeds endured in such tests create a greater demand for oxygen. It is speculated however, that the ability to maintain such speeds at a duration long enough to attain max $\dot{V}O_2$ may only be possible for highly trained runners (Astrand & Rhodahl, 1977; Wilson et al., 1979).

Wilson et al. (1979) attempted to prevent speed from becoming a limiting factor in the horizontal protocol. Two subject groups a) highly trained endurance runners, and b) non-track trained active controls were required to run both a horizontal and a vertical treadmill test protocol. The vertical protocol was very similar to that used by Taylor et al. (1955). The horizontal protocol however, required that the subjects run at a constant speed with work load increments being provided by the addition of 0.5 kg to 1.0 kg weights to a pulley system which applied a horizontal impeding force to the runners. Wilson's data for the

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active controls supported the finding of a stable max $\dot{V}O_2$ value between the two running modes. However, the data for the highly trained endurance runners does not support the conclusion of the previous studies. The horizontal max $\dot{V}O_2$ test was found to produced significantly greater max $\dot{V}O_2$ values than did the vertical protocol for the trained runners. The nature of the horizontal run in Wilson's tests may have been the contributing factor in this difference.

Further, in support of the horizontal protocol, Kasch et al. (1986) used 12 highly trained college male athletes to compare both the horizontal and inclined protocols. Their results showed no significant difference in max $\dot{V}O_2$ between procedures even though the mean grade for the last minute of the inclined protocol was 13.1%. This was in agreement with Sucec (1974) who produced data which indicated that the horizontal treadmill protocol will reliably produce max $\dot{V}O_2$ scores comparable to scores made during the inclined treadmill protocol for both male and female distance runners. The above studies suggest that these max $\dot{V}O_2$ differences from other investigators may be due to age, training, test duration and protocol, number of subjects, or other factors.

In a study examining the potential interaction between training terrain (i.e., hilly vs. flat) and the specific protocol used to determine max $\dot{V}O_2$, Freund et al. (1986) analyzed the interaction between the subjects max $\dot{V}O_2$ obtained on a horizontal protocol and an inclined protocol

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before and after training for 12 weeks on inclined terrain. The two protocols used in determining a subject's max $\dot{V}O_2$ were designed to elicit exhaustion in 8 to 12 minutes. The inclined protocol was an abbreviation of the Bruce protocol, using 2 minute stages. The horizontal protocol also had 2 minute stages starting at 4.0 miles per hour (mph). The speed was then increased to 6.5 mph for the second stage of this protocol and by 1.0 mph for each subsequent stage. Freund's results demonstrated no significant difference in max $\dot{V}O_2$ prior to inclined training between protocols. However, when post-training data were analyzed, it was found that the inclined protocol elicited significantly greater max $\dot{V}O_2$ values ($\underline{p} \leq .05$) compared to those values obtained on the horizontal protocol.

The above suggests that training of specific muscle groups may increase the max $\dot{V}O_2$ by facilitating oxygen transport and by adaptive changes in the metabolic characteristics of the muscle fibers, e.g., the enzyme activities. This means that a test, involving large muscle mass and optimal use of the specifically trained muscle fibers, may elicit the highest value for max $\dot{V}O_2$, when comparing the results obtained by different test procedures (Stromme, Ingjer, & Meens, 1977).

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CHAPTER III

METHODOLOGY

Prior to the initiation of this investigation, approval from the University of Montana Institutional Review Board was obtained. In addition, each subject was given an explanation of the investigation. He was informed as to the purpose of the study, any known risks or discomforts, the benefits to be expected, and his right to terminate any of these tests at any time he wished. Each subject expressed his understanding by signing a statement of informed consent (see Appendix A) as required by the Institutional Review Board. In addition to the informed consent, each subject further completed a medical history form (see Appendix B).

Research Methods

Twenty well-trained male endurance athletes from the University of Montana were used for treadmill testing of maximal oxygen consumption. Each subject was required to perform 4 randomly assigned maximal oxygen uptake treadmill tests. In addition, descriptive data was obtained for each subject including age (yrs), height (cm), weight (kg), and percent body fat. All subjects were further required to

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complete a training log which contained questions concerning their diet, amount of training, sleep, and how they felt prior and during the treadmill test (see Appendices C & D). These training logs helped the researcher determine how the athletes felt about each of the 4 maximal graded exercise tests. Further, they gave valuable insight concerning the athletes condition prior to exercise testing. Laboratory testing was performed during April and May of 1988 in the University of Montana's Human Performance Laboratory.

Maximal Treadmill Tests

The 4 maximal graded exercise treadmill test protocols (see Appendix E) that were studied varied greatly in speed and elevation. All tests were performed on a Quinton Motorized Treadmill Model 643, and included:

The Bruce Test

The subject started at a speed of 1.7 mph on a grade of 10 percent. The grade was then increased by 2 percent for each 3 minute time stage. The speed for each stage increased from 1.7 mph to 2.5 mph to 3.4 mph to 4.2 mph to 5.0 mph to 5.5 mph to 6.0 mph.

The Astrand Test

The Astrand test included a 5 minute warm-up walk at 3.5 mph on a 2.5 percent grade. The subject then ran at a constant speed of 8.5 mph for the entire test. Percent

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grade for the test was initially set at 2.5 and was increased by 2.5 percent every 2 minutes.

The Montana Vertical Test

The subject began walking at a speed of 3.5 mph on a grade of 12 percent. This stage was maintained for 2 minutes after which the speed was increased by 0.5 mph for every minute completed. The grade was held constant at 12 percent.

The North Dakota Horizontal Test

The subject began running at 5 mph. This was maintained for 2 minutes, after which the speed was increased by 1 mph. This new speed was maintained for 2 more minutes and was then increased to 8 mph, which was held for another 2 minutes. After this stage each additional stage was increased 1 mph for every minute completed up to 12 mph. After running at 12 mph for 1 minute each additional stage was increased by .5 mph per minute. The grade was held constant during the entire test at 0 percent.

Prior to each test, while sitting on a stool positioned on the treadmill, the resting athletes pre-test metabolic data was monitored for 3 minutes. A 1 minute transition period followed during which time the initial speed and elevation of the graded exercise treadmill test protocol was adjusted.

Upon termination of the test the subject began an active recovery with both the speed and grade being reduced

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to 3 mph and 0 percent, respectively. After 3 to 5 minutes of active recovery, the treadmill was stopped and the subject continued to be monitored until the heart rate dropped below 100 beats per minute. In order to ensure that adequate recuperation was achieved a minimum of 3 days rest was required between each maximal graded exercise test. A maximum of 6 days rest was allowed between testing.

Oxygen Consumption

All oxygen consumption measurement were obtained every half minute using a Sensormedics Metabolic Measurement Cart. Each subject breathed through a Hans-Rudolf breathing mask which was connected to a mixing chamber. A constant amount of the expired air (500 $mL \cdot min^{-1}$) was pulled from the mixing chamber through a drying column to a Beckman Om-11 oxygen analyzer and a Beckman LB-2 median gas analyzer. Both analyzers were calibrated before each test using gas mixtures of known concentrations. Temperature of the expired air was sensed at the outlet of the mixing chamber. Barometric pressure was measured with a single hybrid package containing a diaphragm and pressure reference, a piezresistive sensor, signal conditioner, and amplifier. Time was measured by a crystal-controlled precision electronic clock.

The timing and sequence of measurements was under the control of an electronic interface and a programmable

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computer. The electronic interface also digitized the signals from the analyzers and transferred the digital values to the computer. The programmable computer oversaw the operation of the measurement cycles, performed all required calculations, and printed the calculated answers. $\dot{V}O2$ was expressed in absolute ($mL \cdot min^{-1}$) and relative ($mL \cdot kg^{-1} \cdot min^{-1}$) terms. The computer further calculated and printed the subjects Pulmonary Ventilation ($L \cdot min^{-1}$) and Respiratory Exchange Ratios.

Heart Rate

Heart rate measurements were recorded during each subjects initial test with a conventional electrocardiogram (ECG) apparatus (Burdick) using a 3 electrode lead configuration. Heart rate measurements were recorded for each succeeding test using a UNIQ-CIC heart watch. This watch recorded heart rate measurements by way of a transmitter, which was fastened to the subjects chest with electrodes. The transmitter sent signals to a receiver, which displayed the athletes heart rate ($b.min^{-1}$). These measurements were recorded during the final 15 seconds of each .5 minute.

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Data Analysis

Data analysis was carried out on VAC computer utilizing the Statistical Programs for the Social Sciences (SPSS). SPSS was used for generation of the descriptive statistics. The basic statistical analysis that was used to compare tests was an analysis of variance for repeated measures (ANOVA). Significance was set at $p \leq .05$.

The Scheff'e a posteriori procedure was then performed to determine how the protocol means differ. Because this statistical test is a very rigorous procedure, the investigator chose to employ a less severe significance level; that is the $p \leq .10$ level was used instead of the $p \leq .05$ level. This being Scheffe's recommendation (Ferguson, 1959).

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CHAPTER IV

RESULTS AND DISCUSSION

Results

Resting descriptive characteristics of the subjects tested in this study are shown in Table 1. Analysis of variance results obtained from the resting data are listed in Table 2. Total group measurements for weight, resting systolic blood pressure, and resting heart rate were considered similar or not significantly ($p \leq .05$) different throughout the entire testing period with all four protocols. A significant difference $F(1,57) = 2.9755$, $p = .039$ was observed when comparing resting diastolic blood pressures between the Bruce protocol and the Montana Vertical protocol. However, it was believed that this observed difference in resting diastolic blood pressure has no practical significance for this study.

To account for adjusting to the laboratory environment as well as for learning and training effects, the order in which the tests were administered was also analyzed. A significant difference in testing order was found to exist

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Table 1

Descriptive Characteristics of Subjects - Resting

Variable	Mean ± SD	
Age (yr)	27.00	± 4.74
Height (cm)	177.30	± 7.01
Weight (kg)	72.78	± 8.87
Body Density	1.0782	± 0.01
Percent Body Fat	9.10	± 2.65

Note. *n* = 20; Values represent mean ± standard deviation.

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Table 2

Analysis of Variance Results - Resting Data

Variable	*df*	F-value	P-value
Weight (kg)	57	.33	.804
RSBP (mmHg)	57	.56	.641
RDBP (mmHg)	57	2.98	.039*
RHR ($b \cdot min^{-1}$)	57	1.12	.347
Test Order	57	3.40	.024*

Note. RSBP = resting systolic blood pressure; RDBP = resting diastolic blood pressure; RHR = resting heart rate; *df* = degrees of freedom; kg = kilogram; mmHg = millimeters of mercury; $b \cdot min^{-1}$ = beats per minute.

* = $p \leq .05$.

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between the Horizontal and Vertical protocols, $F(1,57) = 3.3992$, $p = .024$. This difference concerning sequence demonstrated that the Vertical protocol was more apt to be administered towards the beginning of each individuals testing, while the Horizontal protocol was more apt to be administered towards the end. Since maximum heart rate values for the Horizontal protocol were almost significantly ($p \leq .05$) higher than the other 3 protocols, it was believed that subject motivation to run to a maximum effort was still great at the end of testing. Further, since no significant difference was found to exist between the Vertical and Horizontal protocols it was believed that this observed difference in test order did not influence results, and had no practical significance for this study.

Table 3 lists the resting values obtained for each of the four maximal graded exercise tests. Little variation occurred between tests for mean body weight (kg), resting systolic blood pressure (mmHg), and resting heart rate ($beats \cdot min^{-1}$). However, as mentioned earlier a significant difference ($p \leq .10$) was found to exist for resting diastolic blood pressure when comparing the Bruce and Vertical protocols during post-hoc analysis. Mean resting diastolic pressure (mmHg) $\pm$ standard deviation were 78.70 $\pm$ 8.22, 82.50 $\pm$ 5.02, 83.20 $\pm$ 5.17, and 81.20 $\pm$ 6.88 for the Bruce, Astrand, Vertical and Horizontal protocols, respectively. The order in which the tests were administered was also mentioned as being significantly

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Table 3

Resting Values - Maximal Graded Exercise Tests

Variable	Bruce	Astrand	Vertical	Horizontal
Weight (kg)	72.85 ± 8.61	73.02 ± 8.67	73.12 ± 9.06	73.03 ± 8.95
RSBP (mmHg)	121.60 ± 8.27	124.30 ± 7.44	123.10 ± 6.10	123.40 ± 11.54
RDBP (mmHg)	78.70 ± 8.22	82.50 ± 5.02	83.20 ± 5.17[a]	81.20 ± 8.88
RHR ($b \cdot min^{-1}$)	60.40 ± 9.92	57.85 ± 8.18	60.45 ± 9.85	60.65 ± 12.31
Test Order	2.25 ± 1.02	2.65 ± 1.14	2.00 ± 1.08[b]	3.15 ± 0.99

Note. Mean ± standard deviation; RSBP = resting systolic blood pressure; RDBP= resting diastolic blood pressure; RHR = resting heart rate; kg = kilogram; mmHg = millimeters of mercury; $b \cdot min^{-1}$ = beats per minute.

[a] Significant difference at $p \leq .05$ compared to Bruce; [b] Significant difference at $p \leq .05$ compared to Horizontal

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different. When comparing the Horizontal and Vertical protocols it was found that the Vertical protocol was administered first 6 times while the Horizontal protocol was administered first only two times. Conversely, the Vertical protocol was administered last only three times, while the Horizontal protocol was administered last to nine of the subjects.

Analysis of variance (ANOVA) results obtained from the maximal data (Table 4) showed no significant difference to exist between protocols for Max $\dot{V}E$ ($L \cdot min^{-1}$), $\underline{F}(1,57)$ =.33, $\underline{p}$ = .808; Max RER, $\underline{F}(1,57)$ = .68, $\underline{p}$ = .571; and Max VO_2 ($L \cdot min^{-1}$). $\underline{F}(1,57)$ = 2.22, $\underline{p}$ = .095. Further, while no significant difference ($\underline{p} \leq .05$) was found to exist for maximal heart rate ($b \cdot min^{-1}$), $\underline{F}(1,57)$ = 2.66, $\underline{p}$ = .056, it should be noted that this was very close. A significant difference was found to exist for max $\dot{V}O_2$ ($mL.kg^{-1} \cdot min^{-1}$), $\underline{F}(1,57)$ = 169.20, $\underline{p}$ = .000.

Table 5 lists the mean maximal values obtained for each of the 4 maximal graded exercise tests, (individual maximal values for the 4 maximal protocols may be seen in Appendix F). The mean max $\dot{V}O_2$ ($L \cdot min^{-1}$) $\pm$ standard deviation was 4.63 $\pm$ 0.28, 4.61 $\pm$ 0.41, 4.57 $\pm$ 0.35, and 4.51 $\pm$ 0.42

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Table 4

Analysis of Variance Results - Maximal

Variable	*df*	F-Value	P-Value
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	57	2.22	.095
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	57	3.13	.032*
Max HR ($b \cdot min^{-1}$)	57	2.66	.056
Max $\dot{V}E$ ($L \cdot min^{-1}$)	57	.33	.804
Max RER	57	.67	.571
Time to Max. (Min)	57	169.20	.000*

Note. Max $\dot{V}O_2$ = maximum oxygen uptake; Max $\dot{V}E$ = maximum pulmonary ventilation; RER = respiratory exchange ratio; *df* = degrees of freedom; $L \cdot min^{-1}$ = liters per minute; $mL \cdot kg^{-1} \cdot min^{-1}$ = milliliters per kilogram per minute; $b \cdot min^{-1}$ = beats per minute; min = minutes.

* = $p \leq .05$.

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Table 5

Maximal Values - Maximal Graded Exercise Tests

Variable	Bruce	Astrand	Vertical	Horizontal
Max. $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.63 ± 0.28	4.61 ± 0.41	4.57 ± 0.35	4.51 ± 0.42
Max. $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	64.15 ± 5.99	63.89 ± 6.64	62.96 ± 5.56	62.10 ± 5.11[a]
Max. HR ($b \cdot min^{-1}$)	182.05 ± 9.98	182.15 ± 21.36	184.95 ± 11.91	185.10 ± 9.58
Max. $\dot{V}E$ ($L \cdot min^{-1}$)	154.64 ± 15.91	155.86 ± 21.36	157.13 ± 18.79	155.46 ± 18.61
Max RER	1.17 ± 0.06	1.19 ± 0.06	1.20 ± 0.05	1.19 ± 0.05
Time to Max. (min)	15.62 ± 1.99[b]	11.76 ± 1.23	10.11 ± 1.30	10.75 ± 1.17

Note. Mean ± standard deviation; Max $\dot{V}O_2$ = maximum oxygen uptake per minute; Max $\dot{V}E$ = maximum pulmonary ventilation per minute; Max RER = respiratory exchange ratio; $L \cdot min^{-1}$ = liters per minute; $mL \cdot kg^{-1} \cdot min^{-1}$ = milliliters per kilogram per minute; $b \cdot min^{-1}$ = beats per minute; min = minutes.

[a] Significant difference at $p \leq .05$ compared to Bruce; [b] Significant difference at $p \leq .05$ compared to Astrand, Vertical, and Horizontal.

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for the Bruce, Astrand, Vertical, and Horizontal protocols, respectively. A significant difference was found to exist between the Bruce and Horizontal protocols for Max. $\dot{V}O_2$ when expressed relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$). The relative mean max $\dot{V}O_2$ values for each of the four tests were 64.16 ± 5.99, 63.89 ± 6.64, 62.96 ± 5.56, and 62.1 ± 5.11. The mean Max heart rate ($beats \cdot min^{-1}$) ± standard deviation were 182.05 ± 9.98, 182.15 ± 9.04, 184.95 ± 11.91, and 185.10 ± 9.58, respectively. According to this heart rate data and subjective observations motivation was considered excellent throughout the entire testing period. Post-hoc comparisons, further demonstrated a significant ($p \leq .10$) difference for test duration to exist between the Bruce protocol and the other three treadmill protocols. The mean test duration times ± standard deviation were 15.62 ± 1.99, 11.78 ± 1.23, 10.11 ± 1.30, and 10.75 ± 1.17 for the Bruce, Astrand, Vertical, and Horizontal protocols, respectively.

Discussion

Presently, no one treadmill protocol has been considered to be superior at measuring maximal $\dot{V}O_2$ values. Numerous protocols have been developed in an attempt to elicit these values, and the majority of these protocols use increases in speed and grade to achieve maximal levels of performance. However, the testing procedure varies from one laboratory to another and the crucial question remains.

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as whether experimental variation of the physical work condition (i.e., treadmill, in this case) could influence maximal physiological parameters. If so, it would mean that any two maximal $\dot{V}O_2$ values elicited under different work conditions would be confounded (Molnar et al., 1974).

This study attempted to determine whether standard treadmill tests such as the Bruce protocol (the most widely used of the physician directed maximal exercise tests) and Astrand protocol (the Astrand protocol is widely used in Europe for testing both normal populations and athletes) are inappropriate for measuring Max. $\dot{V}O_2$ values in highly trained endurance athletes. The reason being that highly trained endurance athletes may have almost double the aerobic capacity of a sedentary group (McArdle et al., 1986). Because of this increased aerobic capacity it was speculated that a standard treadmill test was not intense enough for the endurance athlete. It was believed that the duration of these standard tests lasted too long causing the endurance athlete to terminate the test due to muscular fatigue, rather than max $\dot{V}O_2$. Review of the literature shows that the severity and duration of the protocol influence results as they affect anaerobic metabolism, localized fatigue, and temperature regulation (Knowlton et al., 1977). When the attainment of maximum oxygen uptake appears limited by factors other than central circulatory dynamics, a peak $\dot{V}O_2$ is observed rather than a max $\dot{V}O_2$ (McArdle et al., 1986).

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Results of this study indicated that the standard treadmill protocols (Bruce, Astrand) which generally produced a longer test duration than the two more intense protocols (Montana Vertical, North Dakota Horizontal) elicited higher but not significantly greater mean max $\dot{V}O_2$ ($L \cdot min^{-1}$) values. When expressed in relation to body weight, the Bruce protocol actually produced significantly greater max $\dot{V}O_2$ values than did the Horizontal protocol. Further, the Bruce protocol which had a significantly longer test duration than the Astrand, Vertical, and Horizontal protocols produced the highest mean absolute and relative max $\dot{V}O_2$ values of any of the tests administered in this study. The Astrand protocol which had the second longest mean test duration produced the second highest mean Max. $\dot{V}O_2$ values.

These results reject the first two hypothesis of this study, which stated that the two more intense protocols (Montana Vertical, and North Dakota Horizontal) would elicit significantly greater max $\dot{V}O_2$ values as compared to the two standard protocols (Bruce, Astrand). Further, these results suggest that the two standard treadmill protocols (Bruce, Astrand) are capable of measuring valid maximal $\dot{V}O_2$ values in highly trained endurance athletes. The longer test duration of the standard protocols does not appear to be producing muscular fatigue factors great enough to limit the endurance athletes maximal cardiovascular response.

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Statistical comparisons were further made between the three inclined treadmill protocols (Bruce, Astrand, Montana Vertical) and the North Dakota Horizontal protocol to determine whether an inclined protocol would elicit higher max $\dot{V}O_2$ values. While the results of this study generally showed higher absolute max $\dot{V}O_2$ values to exist for the three inclined protocols no significant difference was found to exist between the inclined and horizontal protocols for max $\dot{V}O_2$ ($L \cdot min^{-1}$). When max $\dot{V}O_2$ was expressed relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$) a significant difference ($\underline{p} \leq .10$) was found to exist between the Bruce and Horizontal protocols.

This finding rejects the third hypothesis of this study, which stated that endurance athletes will attain significantly greater max $\dot{V}O_2$ values on the Montana Vertical protocol as compared to the North Dakota Horizontal protocol. However, the significant difference found to exist between the Bruce and Horizontal protocols for relative max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) supports the results of Molnar et al. (1974), which indicated a directionality of higher max $\dot{V}O_2$ values with increasing grades (the Bruce protocol had the highest mean terminal grade (19.4%) of the three inclined protocols). This suggests that greater muscle mass utilized at steeper, more intense grades would have some effect on the level of max $\dot{V}O_2$. Molnar further emphasized that if peripheral factors cannot fully explain the higher maximal $\dot{V}O_2$ at the higher grade, then

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consideration should be given to the role of the sympathetic (accelerator) nerves in augmenting blood circulation and thereby promoting oxygen transport. It is conceivable that the higher intensity of effort at the higher treadmill grades induces nerve activity which in turn serves to enhance oxygen transport and thus accounts for a higher max $\dot{V}O_2$.

Since all of the subjects tested in this study were from and trained around the Missoula, Montana area, a very mountainous county, the specificity of training effect may help to explain the greater Max. $\dot{V}O_2$ ($L \cdot min^{-1}$)($mL \cdot kg^{-1} \cdot min^{-1}$) results obtained on the Vertical protocols as compared to the Horizontal protocol. This is important because it is only those muscles that are stressed during the endurance activity which exhibit such adaptations as increased capillary density, concentration of mitochondrial protein, and glycogen storage. Costill, Jansson, Gollnick, & Saltin, (1974) investigating glycogen depletion during inclined and horizontal running, suggested that the involvement of leg muscles is different for horizontal and inclined running. During uphill running, glycogen breakdown was much greater, especially in the vastus lateralis muscle compared to running horizontally. This was explained by increased work done by the vastus lateralis in elevating the body during uphill running. Therefore, if intramuscular changes are to contribute to an increased max $\dot{V}O_2$, the laboratory test protocols must

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utilize these trained muscles if valid max $\dot{V}O_2$ measurements are to be attained.

The training status of the athletes tested in this study is another factor which may help to explain the lower max $\dot{V}O_2$ values elicited on the horizontal protocol as compared to the vertical protocols. The reason for this may be that only highly trained runners may be able to maintain the leg speeds necessary at a duration long enough to elicit maximum cardiorespiratory values on the horizontal protocol (Da-Costa et al., 1984).

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CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Twenty well-trained male endurance athletes were used for treadmill testing of maximal oxygen consumption. Each subject was required to perform 4 randomly assigned maximal oxygen uptake treadmill tests. These treadmill tests consisted of two standard protocols (Bruce, Astrand) and two developed, more intense protocols (Montana Vertical, North Dakota Horizontal). All oxygen consumption measurements were obtained every .5 minutes using a sensor medics metabolic measurement cart. Heart rate measurements were recorded during each subject's initial test with a conventional apparatus (Burdick) using a 3-electrode lead configuration. Heart rate measurements were recorded for each succeeding test using a UNIC-CIC heart watch. These measurements were recorded during the final 15 seconds of each .5 minute.

Data analysis was carried out on the VAC computer utilizing the Statistical Programs for the Social Sciences (SPSS). SPSS was used for generation of the descriptive statistics. The analysis of variance for repeated measures was used to determine if a significant difference in max

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$\dot{V}O_2$ resulted from any of the 4 treadmill protocols. This was followed with the Scheff'e a posteriori procedure which was performed to help determine how the protocols differ.

The primary purpose of this study was to determine whether standard treadmill protocols (protocols set up for the non athlete) were appropriate for measuring maximal values in well trained endurance athletes. Because the endurance athlete may have double the aerobic capacity of a sedentary group, it was felt that the duration of these standard protocols (Bruce, Astrand) ran on so long that the endurance athlete ended up terminating these tests due to local muscular fatigue rather than reaching his max $\dot{V}O_2$.

This study indicated that the Bruce and Astrand protocols which generally produced a longer test duration than the Vertical and Horizontal protocols elicited higher but not significantly greater mean absolute max $\dot{V}O_2$ ($L \cdot min^{-1}$) values. The Bruce protocol actually produced significantly greater max $\dot{V}O_2$ values when expressed relative to body weight, than did the Horizontal protocol. This suggests that the two standard protocols are capable of measuring valid maximal $\dot{V}O_2$ values in highly trained endurance athletes.

This study further compared a horizontal protocol to three inclined protocols (Bruce, Astrand, Vertical). This was performed to help determine which treadmill graded exercise test elicits higher max $\dot{V}O_2$ values.

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It was found that the vertical protocols elicited greater mean max $\dot{V}O_2$ results. The Bruce protocol actually elicited significantly greater max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) values as compared to the North Dakota Horizontal protocol.

Conclusions

Within the limits of the methods used this study indicated that the standard treadmill protocols (Bruce, Astrand) actually produced higher, but not significantly greater values than the two protocols which were designed to have a shorter duration (Montana Vertical, North Dakota Horizontal). This suggests that the two standard protocols are capable of measuring valid maximal $\dot{V}O_2$ values in highly trained endurance athletes. Further, the longer test duration of these protocols does not appear to be producing muscular fatigue factors great enough to limit the athletes' maximal cardiovascular capacity.

When the vertical protocols (Bruce, Astrand, Vertical) were compared to the North Dakota Horizontal protocol , a significant difference was found to exist between the Bruce and Horizontal tests and max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$). This suggests that experimental manipulations of the treadmill protocol can influence max $\dot{V}O_2$ results. Therefore, max $\dot{V}O_2$ as a criterion for 1) comparing individuals or groups 2) when applying the results of these tests to designing individualized conditioning programs, and 3) when following subjects over a period of time, can only be valid if the

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conditions under which it is elicited are kept standardized. Because of the above findings, this researcher would recommend that standard treadmill conditions be used throughout, for all subjects.

When factors such as test duration, subject comfort, and ease of administration are considered, this author found that the Astrand and Vertical protocols were actually more appropriate for testing the endurance athlete than the Bruce protocol. It was noted in many of the training logs, that many of the athletes were complaining of local muscular pain in their lower backs, and calves while running the Bruce test. Further, the Astrand and Vertical protocols were much easier to administer than the Bruce protocol. This is because the Bruce protocol must be adjusted for both speed and grade, while the Astrand protocol must only be adjusted for grade and the Vertical protocol needs only to be adjusted for speed. Test duration for the Bruce protocol was further found to be significantly greater than that of the Astrand and Vertical protocols, while no significant difference was found among these tests for max $\dot{V}O_2$ when expressed in absolute ($L \cdot min^{-1}$) or relative ($mL \cdot kg^{-1} \cdot min^{-1}$) terms.

Recommendations

1. Future studies should divide the subject population up into separate fitness levels to more

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effectively determine the effects of treadmill duration on max $\dot{V}O_2$.

2. Future studies should divide the subject population up into separate fitness levels to more effectively determine the difference between horizontal and vertical protocols on max $\dot{V}O_2$ values.

3. More control over the subjects in regard to their activities and general health habits is certainly desirable for future investigations.

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APPENDIX A

HUMAN INFORMED CONSENT

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Human Informed Consent

You will perform four different maximal exercise tests on a motor driven treadmill. The exercise intensity will begin at a level you can easily accomplish and will be advanced in stages. We may stop the test at any time because of signs of fatigue or you may stop the test at any time you wish because of personal feelings of fatigue or discomfort.

There exists the possibility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorder or heartbeat, and in rare instances, heart attack or death. Every effort will be made to minimize these through the preliminary examination and by observations during testing. Emergency equipment is available to deal with the unusual situations which may arise.

The information provided by the assessment of maximal oxygen uptake provides a quantitative statement of an individual's capacity for aerobic energy transfer. As such, it is one of the more important factors determining one's ability to sustains high intensity exercise for longer than 4 to 5 minutes.

Any questions about the procedure used in the exercise test are encouraged. If you have any doubts or questions, please ask us for further explanations.

Your permission to perform this exercise test is voluntary. You are free to deny consent if you desire.

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

________________________ ______________________________

Date Signature

____

Witness

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APPENDIX B

MEDICAL HISTORY FORM

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MEDICAL HISTORY FORM

Name: ______________________________

SS #: ______________________________

Name of your physician: ___________________________________

List the date of your last:

Physical Exam: ____________________ Surgery: ____________________

EKG: ____________________

1. Have you been told by a doctor that you have or have had any of the following (please check each response):

Yes	No		Yes	No	
( )	( )	Rheumatic fever	( )	( )	High blood pressure
( )	( )	An enlarged heart	( )	( )	Abnormal EKG pattern
( )	( )	Epilepsy	( )	( )	Diabetes
( )	( )	Heart or vascular disease	( )	( )	Hyperuricemia (high uric acid levels)
( )	( )	Metabolic disorders	( )	( )	Varicose veins
( )	( )	Heart murmur	( )	( )	Stroke
( )	( )	Lung or pulmonary disorders	( )	( )	Allergies Specify: ________________
( )	( )	Thrombophlebitis (blood clots)	( )	( )	Abnormally high blood lipids (cholesterol or triglycerides levels)

2. Please list any drugs, medication or dietary supplements PRESCRIBED by a physician that you are currently taking:

____

____

____

____

3. Is there a history of heart disease, heart attack, elevated cholesterol levels, high blood pressure or stroke in your immediate family (grandparents, parents, brothers, and sisters) before the age of 60? Yes ( ) No ( )

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4. Do you smoke now? Yes ( ) No ( )
   a. If yes, how many cigarettes do you smoke per day? ____
   b. If no, have you ever smoked?
   ( ) Yes ( ) No
      A. How long ago did you quit? ____ years.

5. Are you currently under a great deal of stress either at work, school, or personally?
   ( ) Yes ( ) No

6. Do you actively relieve stress through exercise, meditation or other methods? ( ) Yes ( ) No.

7. Are you currently on a regular exercise program?
   ( ) Yes ( ) No

   If yes, check the following:
   Type of exercise: ( ) walking ( ) bicycling ( ) tennis

   ( ) aerobics ( ) swimming ( ) racquetball

   ( ) other ______________________

   Frequency per week: ( ) 1-2 times/week ( ) 3-4 times/week
   ( ) 5 or more times/week

   Duration (each day): ( ) < 15 minutes ( ) 15-30 minutes
   ( ) 30-45 minutes ( ) > 45 minutes

8. While exercising do you ever feel limited by (if yes, state type of activity you are performing when this arises):

	Yes	No	
a. Breathing	( )	( )	Activity: ____________
b. Chest, arm or neck pain	( )	( )	Activity: ____________
c. Low back pain	( )	( )	Activity: ____________
d. Pain in leg, relieved by rest	( )	( )	Activity: ____________
e. Side aches	( )	( )	Activity: ____________
f. Lower leg pain Front - Shin splints Back - Achilles	( )	( )	Activity: ____________
g. Extreme long-lasting fatigue	( )	( )	Activity: ____________

The answers to this questionnaire are true and complete and to the best of my knowledge I am in good health.

Signed:______________________ Date:__________

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APPENDIX C

TRAINING LOG - DAY OF TEST

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Training Log - Day of Test

Name: Date:

What did you do for exercise today? ______________________________

____

____

Did you exercise before the test? If yes, what did you do? _____

____

____

____

How long before the test did you eat? ___________________________

____

Did you feel tired prior to the test? ___________________________

____

How did you feel during the test? ______________________________

____

____

Were you motivated to do the test?______________________________

____

Comments on the test.

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APPENDIX D

TRAINING LOG - DAYS BETWEEN TESTING

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Training Log - Days Between Testing

Name: Date:

What did you do for exercise today? ____________________

____

____

How did you feel? ____________________

____

Did you get plenty of rest? ____________________

____

Are you eating properly? ____________________

____

How do you feel in general? ____________________

____

Comments:

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Date:

What did you do for exercise today? ______________________________

____

____

How did you feel? ____

____Did you get plenty of rest? ____

____

Are you eating properly?____

____

How do you feel in general? _____________________________________

____

Comments:

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Date:

What did you do for exercise today? ______________________________

____

____

How did you feel? ______________________________________

____________________________________Did you get plenty of

rest? ____

____

Are you eating properly?_________________________________

____

How do you feel in general? ______________________________

____

Comments:

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Date:

What did you do for exercise today? ____________________________

____

____

How did you feel? ____

____Did you get plenty of

rest? ____

____

Are you eating properly?_______________________________________

____

How do you feel in general? ____________________________________

____

Comments:

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APPENDIX E

MAXIMAL GRADED EXERCISE TREADMILL TEST PROTOCOLS

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Maximal Graded Exercise Treadmill Test Protocols

Astrand Protocol

Min	Speed (mph)	Grade(%)
1-5	3.5	2.5
5-7	8.5	2.5
7-9	8.5	5.0
9-11	8.5	7.5
11-13	8.5	10.0
13-	8.5	12.5

Note: min = minutes; mph = miles per hour; % = percent.

Bruce Protocol

Min	Speed (mph)	Grade(%)
1-3	1.7	10.0
3-6	2.5	12.0
6-9	3.4	14.0
9-12	4.2	16.0
12-15	5.0	18.0
15-18	5.5	20.0
18-21	6.0	22.0

Note: min = minutes; mph = miles per hour; % = percent.

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Montana Vertical Protocol

Min	Speed (mph)	Grade(%)
1-2	3.5	12.0
3	4.0	12.0
4	4.5	12.0
5	5.0	12.0
6	5.5	12.0
7	6.0	12.0
8	6.5	12.0

Note: Speed continues to increase by .5 mph for every minute completed; Grade remains constant at 12%; min= minutes; mph = miles per hour; % = percent.

North Dakota Horizontal Protocol

Min	Speed (mph)	Grade(%)
1-2	5.0	0
2-4	6.0	0
4-6	8.0	0
7	9.0	0
8	10.0	0
9	11.0	0
10	12.0	0

Note: Speed increases by .5 mph for every minute completed after 12 mph; Grade remains constant at 0%; min = minutes; mph = miles per hour; % = percent.

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APPENDIX F

INDIVIDUAL MAXIMAL DATA FOR THE FOUR MAXIMAL GRADED EXERCISE TESTS

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	Bruce	Astrand	Vertical	Horizontal
Subject 1				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.33	4.06	4.42	4.11
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	74.20	69.80	76.30	69.60
Max HR ($b \cdot min^{-1}$)	196.00	189.00	199.00	201.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	152.40	148.10	139.10	140.70
Max RER	1.18	1.23	1.19	1.15
Time to Max (min)	17:45	13:30	12:00	13:10
Subject 2				
Max $\dot{V}O_2$ ($L.min^{-1}$)	4.71	4.59	4.49	4.17
Max VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	72.00	69.80	69.60	64.10
Max HR ($b \cdot min^{-1}$)	190.00	185.00	189.00	182.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	156.50	154.70	154.10	147.20
Max RER	1.14	1.17	1.16	1.19
Time to Max (min)	17:10	13:00	11:20	11:10
Subject 3				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	5.04	5.41	5.49	5.28
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.70	59.00	59.20	57.90
Max HR ($b \cdot min^{-1}$)	182.00	185.00	181.00	188.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	171.12	199.80	190.90	184.00
Max RER	1.21	1.26	1.24	1.31
Time to Max (min)	15:15	11:43	9:15	10:10
Subject 4				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.53	4.62	4.54	4.57
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	61.50	64.40	61.60	63.10
Max HR ($b \cdot min^{-1}$)	186.00	183.00	192.00	189.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	144.40	139.00	165.10	153.10
Max RER	1.26	1.11	1.31	1.26
Time to Max (min)	16:00	12:15	11:00	12:00

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	Bruce	Astrand	Vertical	Horizontal
Subject 5				
Max $\dot{V}O_2$ (L·min^{-1})	4.90	5.02	4.73	4.67
Max $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	70.40	72.10	67.60	67.30
Max HR (b·min^{-1})	187.00	181.00	182.00	185.00
Max $\dot{V}E$ (L·min^{-1})	147.30	153.20	158.00	160.60
Max RER	1.10	1.14	1.23	1.14
Time to Max (min)	15:30	12:15	10:00	10:40
Subject 6				
Max $\dot{V}O_2$ (L·min^{-1})	4.46	4.52	4.62	4.38
Max $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	60.40	61.60	62.40	59.50
Max HR (b·min^{-1})	178.00	177.00	183.00	178.00
Max $\dot{V}E$ (L·min^{-1})	150.90	146.70	150.00	146.80
Max RER	1.31	1.20	1.16	1.22
Time to Max (min)	15:45	11:30	9:00	10:30
Subject 7				
Max $\dot{V}O_2$ (L·min^{-1})	4.58	4.62	4.44	4.30
Max $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	64.50	65.70	63.07	60.40
Max HR (b·min^{-1})	165.00	170.00	171.00	170.00
Max $\dot{V}E$ (L·min^{-1})	152.10	143.00	144.10	151.00
Max RER	1.13	1.12	1.12	1.19
Time to Max (min)	16:33	11:55	10:15	11:30
Subject 8				
Max $\dot{V}O_2$ (L·min^{-1})	4.67	4.67	4.47	4.54
Max $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	65.80	64.20	60.70	64.40
Max HR (b·min^{-1})	195.00	197.00	197.00	197.00
Max $\dot{V}E$ (L·min^{-1})	151.62	154.40	155.80	147.10
Max RER	1.18	1.16	1.26	1.17
Time to Max (min)	15:53	11:30	10:10	11:30

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	Bruce	Astrand	Vertical	Horizontal
Subject 9				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.85	4.32	4.53	4.57
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	63.60	56.30	60.10	59.80
Max HR ($b \cdot min^{-1}$)	206.00	199.00	210.00	204.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	175.58	175.10	180.00	169.30
Max RER	1.02	1.18	1.18	1.14
Time to Max (min)	14:53	11:19	10:14	10:25
Subject 10				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.02	3.69	3.99	3.77
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	56.40	51.70	56.20	52.90
Max HR ($b \cdot min^{-1}$)	176.00	192.00	190.00	188.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	142.00	137.60	147.30	144.90
Max RER	1.26	1.26	1.22	1.21
Time to Max (min)	14:00	10:15	8:18	9:00
Subject 11				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.77	4.59	4.61	4.52
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	62.50	61.60	62.60	60.60
Max HR ($b \cdot min^{-1}$)	190.00	192.00	197.00	196.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	158.50	167.50	178.30	167.70
Max RER	1.21	1.22	1.22	1.22
Time to Max (min)	14:31	10:00	9:30	9:40
Subject 12				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.64	5.20	4.55	4.78
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	63.70	71.50	62.20	65.80
Max HR ($b \cdot min^{-1}$)	172.00	174.00	176.00	177.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	162.00	178.60	170.90	176.90
Max RER	1.20	1.19	1.20	1.22
Time to Max (min)	15:30	12:45	11:00	12:00

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	Bruce	Astrand	Vertical	Horizontal
Subject 13				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.99	4.89	4.89	4.66
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	65.80	68.70	64.00	61.00
Max HR ($b \cdot min^{-1}$)	178.00	178.00	178.00	180.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	181.80	169.00	164.50	166.80
Max RER	1.21	1.23	1.26	1.23
Time to Max (min)	17:20	13:00	10:52	10:28
Subject 14				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.12	3.98	3.98	3.86
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	60.50	55.40	55.40	55.10
Max HR ($b \cdot min^{-1}$)	173.00	173.00	170.00	172.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	127.20	100.20	120.70	108.40
Max RER	1.17	1.33	1.14	1.14
Time to Max (min)	14:00	10:00	8:00	9:00
Subject 15				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.64	4.57	4.44	4.83
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	70.90	69.40	66.70	72.30
Max HR ($b \cdot min^{-1}$)	161.00	168.00	173.00	171.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	128.00	148.20	140.80	145.40
Max RER	1.12	1.20	1.23	1.11
Time to Max (min)	17:03	13:45	11:00	12:30
Subject 16				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.53	4.51	4.77	4.33
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	63.00	64.00	66.50	60.30
Max HR ($b \cdot min^{-1}$)	189.00	189.00	195.00	187.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	153.30	143.90	169.60	149.10
Max RER	1.19	1.16	1.22	1.28
Time to Max (min)	15:00	11:45	9:48	9:43

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	Bruce	Astrand	Vertical	Horizontal
Subject 17				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.62	4.67	4.65	4.68
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	55.90	57.00	55.90	56.30
Max HR ($b \cdot min^{-1}$)	181.00	171.00	171.00	192.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	172.80	175.80	167.80	176.90
Max RER	1.17	1.22	1.19	1.24
Time to Max (min)	13:50	10:00	8:30	9:20
Subject 18				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.69	4.93	4.33	4.49
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	68.30	70.70	63.50	65.50
Max HR ($b \cdot min^{-1}$)	193.00	186.00	198.00	182.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	131.91	147.60	116.97	141.10
Max RER	1.09	1.11	1.10	1.13
Time to Max (min)	11:00	12:13	10:37	10:00
Subject 19				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.45	4.35	4.22	4.12
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	73.40	71.80	71.00	68.70
Max HR ($b \cdot min^{-1}$)	184.00	179.00	178.00	180.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	153.82	150.40	152.80	143.90
Max RER	1.12	1.12	1.16	1.15
Time to Max (min)	21:00	13:00	13:00	11:46
Subject 20				
Max $\dot{V}O_2$ ($L \cdot min^{-1}$)	5.13	5.01	5.19	5.53
Max $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	55.70	53.10	54.70	57.40
Max HR ($b \cdot min^{-1}$)	173.00	175.00	169.00	183.00
Max $\dot{V}E$ ($L \cdot min^{-1}$)	179.60	184.30	170.80	188.40
Max RER	1.22	1.22	1.12	1.13
Time to Max (min)	14:35	10:30	8:30	10:48

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