A COMPARISON OF TWO DIFFERENT TREADMILL PROTOCOLS IN MEASURING MAXIMAL OXYGEN CONSUMPTION IN HIGHLY TRAINED DISTANCE RUNNERS

Ryan Adam Vanhoy

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Approved by:

Claudio L. Battaglini, Ph.D.

Robert G. McMurray, Ph.D.

Edgar W. Shields, Ph.D.

ABSTRACT

RYAN ADAM VANHOY: A comparison of two different treadmill protocols in measuring maximal oxygen consumption in highly trained distance runners
(Under the direction of Dr. Claudio L. Battaglini)

The purpose of this study was to prospectively investigate the specificity effect of two different treadmill protocols on maximal oxygen consumption (VO_{2max}) in highly-trained distance runners (n=16). The secondary purpose examined if the ventilatory threshold (VT) attained during different protocols occurred at the same percent of VO_{2max} (% VO_{2max} @ VT). After a familiarization session performing the Bruce Protocol, VO_{2max} was evaluated using two graded treadmill protocols; a horizontal (increment in speed only) ($SOVO_{2max}$) and inclined (constant speed with increment in grade only) ($GOVO_{2max}$). VO_{2max} values were significantly higher from the $GOVO_{2max}$ in comparison to the $SOVO_{2max}$ protocol (76.1 and 71.2 mLO_2/kg/min, p=. 005). The % VO_{2max} @ VT was not significantly different between the $GOVO_{2max}$ and $SOVO_{2max}$ protocols. The results indicate that, based on runner specialty (flat versus hill runners), either $SOVO_{2max}$ or $GOVO_{2max}$ protocols can be used to determine the % VO_{2max} @ VT in highly-trained distance runners.

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CHAPTER I

INTRODUCTION

Measuring maximal oxygen consumption (VO_{2max}) via treadmill testing is a popular procedure for testing an individual's cardiopulmonary function and providing subsequent information for the design of exercise prescription/ exercise training (Balady et al., 2010). This type of testing is commonly used in the world of endurance athletics to determine an athlete's maximal cardiopulmonary capacity prior to training, so it can be used for a subsequent evaluation of the efficacy of the training methodology. In other words, this procedure helps determine the athlete's ability to produce energy aerobically, a necessary characteristic for success in endurance events (Bassett and Howley, 1997). The physiological information that can be attained from a VO_{2max} test can also be translated into the determination of meaningful training intensities and thresholds for athletes and coaches to use in the prescription of specific exercise training methods for improved performance (Londeree, 1986).

In order to have specific, pertinent physiological information that will translate to success in a given event, it is imperative that the nature of the chosen exercise test be as specific to the environment of the event as possible. Often, runners have certain characteristics that make them better suited for certain types of running events. Some runners are better hill climbers while others find their niche on the flat ground, often excelling at track events. Therefore, the selection of the type and characteristics of an exercise test may influence the precision of assessing VO_{2max} of an endurance athlete, thus, compromising the ability for the determination of precise exercise training prescriptions.

Previous studies have produced conflicting results when comparing horizontal and inclined graded treadmill protocols designed to assess VO_{2max}. Taylor et al. (1955) showed that an inclined treadmill protocol elicited higher VO_{2max} values than a horizontal protocol. Other studies have reported higher VO_{2max} values recorded during horizontal protocols as opposed to inclined protocols (Hermansen and Saltin, 1969). Furthermore, other studies in well-trained males have also shown that there was no difference between horizontal and inclined graded treadmill protocols in measuring VO_{2max} (Kasch, Wallace, Huhn, Krogh, and Hurl, 1976). These conflicting results may be due to the heterogeneity of the subjects tested in regards to fitness levels as well as sports specific characteristics. To date, a study of this nature has not been conducted in highly trained distance runners. Looking at this group of athletes specifically could provide new, meaningful data to add to the current body of literature on this topic. A study investigating the potential differences in VO_{2max} determination between two different VO_{2max} testing protocols in highly trained distance runners may also provide clinical information to coaches and athletes searching for ways to maximize the precise determination of training intensities. This could translate into better physiological responses to training and the ability to perform better in competition.

Statement of Purpose

The primary purpose of this study is to compare VO_{2max} values obtained using two different VO_{2max} graded treadmill tests; a horizontal (increment in speed only) protocol ($SOVO_{2max}$) and inclined (constant speed with increment in grade only) protocol ($GOVO_{2max}$).

A secondary purpose is to determine if the ventilatory threshold attained during these tests occur at the same proportion of VO_{2max}.

Hypotheses

H1: There will be no significant difference in maximal oxygen consumption (VO_{2max}) between the $SOVO_{2max}$ and $GOVO_{2max}$ treadmill testing protocols.

H2: There will be no significant difference in the $\%VO_{2max}$ at which the ventilatory threshold occurs between the $SOVO_{2max}$ and $GOVO_{2max}$ protocols.

Limitations

The amount of sleep that each subject got each night, as well as dietary intake was not controlled. The subject provided pre-testing information before each trial to assess whether sleep and dietary patterns were consistent. The current training phase of each subject was also not controlled for in this study.

Delimitations

All participants were highly trained long distance runners. All recruited subjects were also male. Hydration status was monitored with urine specific gravity testing before each trial. Start time for all trials was consistent within each subject to control for hormonal changes that occur throughout the day.

Definition of Terms

Highly Trained Distance Runners: long distance runners who have been training at a minimum volume of 50 miles per week for at least 6 months.

Maximal Cardiorespiratory Exercise Test (VO_{2max} Test): graded exercise test designed to increase exercise intensity by stages, allowing a subject to reach their maximal capacity for aerobic exercise – can be performed on a treadmill, cycle, or many other modes of exercise. For the sake of this experiment, max tests will be conducted on treadmills.

Maximal Oxygen Consumption (VO_{2max}): the maximum amount of oxygen that the body can take in, transport, and utilize in the working muscle to produce energy aerobically.

Ventilatory Threshold (VT): the point during exercise in which there is an exponential increase in pulmonary ventilation relative to the intensity of exercise and/or oxygen consumption; often reported as a percentage of an individual's $VO_{2max.}$ VT will be determined using the modified V-slope method in this experiment (Appendix VI).

Bruce maximal oxygen consumption test protocol (Bruce Protocol): a commonly used maximal oxygen consumption treadmill protocol that elicits changes in both speed and grade at the same time until the subject reaches a maximal effort. This protocol will be used as a familiarization trial for all subjects in this study.

$SOVO_{2max}$ (Speed Only VO_{2max} Graded Treadmill Test Protocol): protocol for measuring VO_{2max} using incremental increases in speed while maintaining a constant grade of 0%.

$GOVO_{2max}$ (Grade Only VO_{2max} Graded Treadmill Test Protocol): protocol for measuring VO_{2max} using incremental increases in grade while maintaining speed constant.

Assumptions

All subjects in this experiment abstained from alcohol, drugs, or any other ergogenic aid during the period of the study that could affect the results of the study. Subjects also maintained a similar diet between testing trials, avoiding any drastic deviations from their standard dietary regimen.

Significance

Performance and success in long distance running is greatly influenced by the training methods and preparation employed during the weeks and months leading up to a major competition. In planning for this training build-up, it is fundamental for coaches to have first-hand knowledge of an athlete's cardiorespiratory fitness level, as this information can help in the designing and implementation of effective training programs for peak performance.

In long distance running, athletes compete at many different types of events, ranging from track races to cross country and road competitions. An individual's ability to perform in a certain type of event can vary greatly depending on their varying physiological characteristics.

In testing these athletes, it is important to produce meaningful data that is measured in a way most specific to their target event. This ensures that the physiological information used to formulate training plans and methodology is the most precise for allowing the determination of accurate exercise training intensity thresholds. Therefore, it is necessary to examine whether VO_{2max} testing is consistent among different protocols. By examining the same athletes on one protocol that increases only in speed and one protocol that holds speed constant but varies in grade, it is possible to see if the type of protocol used can affect the determination of $VO_{2max.}$ The results of this investigation will begin to clarify the specificity of testing practices so coaches and athletes involved in long distance running can improve the way they determine exercise intensity training thresholds. If the results are ruled the same between the two protocols, it will inform both coaches and athletes that the type of protocol used is not of great consequence when determining training thresholds and monitoring training progress. However, if differences between testing protocols are observed, coaches and athletes will be able to choose the most appropriate testing methodology to ensure maximal precision for the determination of exercise training intensity prescription, as well as more precise monitoring of the athletes' responses to training programs and workouts throughout a training cycle.

CHAPTER II

REVIEW OF LITERATURE

This literature review was divided into six sections. The first section provides an overview of oxygen consumption and its relationship with exercise. The second section reviews the different testing procedures that have been developed for measuring maximal oxygen consumption. The third section reviews and compares the different treadmill protocols that have been used to measure maximal oxygen consumption, focusing on the specificity of the method employed for testing. The fourth section reviews the current body of literature on horizontal and inclined treadmill testing protocols, comparing and contrasting research findings. The fifth section provides an overview of muscle activation and fiber type recruitment that occurs during running both uphill and flat, as well as the fiber type distribution that has been observed in elite long distance runners. The final section reviews the applicability of VO_{2max} testing in developing training programs for long distance runners, including the determination and application of ventilatory threshold data.

Oxygen Consumption

Oxygen consumption refers to the process of an individual breathing in oxygen, transporting it to the working muscle, and using it to generate energy aerobically (Mitchell and Blomquist, 1971). During exercise, the oxygen that is brought in and utilized allows the body to meet the energy demands of the specific level of exercise intensity. As a result, this concept has become one of much interest in the field of exercise physiology, particularly maximal oxygen consumption. Maximal oxygen consumption, or VO_{2max}, is the maximal amount of oxygen an individual can bring in and utilize during exercise (Hill and Lupton, 1923). Research on the topic of maximal oxygen consumption has been around since the infancy of exercise physiology. In 1923, Hill and Lupton conducted running experiments where they determined that oxygen consumption increased linearly with an increase in running speed. Ultimately, they found that oxygen consumption reached a peak value and plateaued, even with an increase in workload. By conducting running tests where the subject reached a plateau in VO_{2max}, even when the speed of running was increased, it became clear that oxygen consumption had a maximal limit on an individual level (Hill and Lupton, 1923). From this research, they concluded that oxygen consumption reached a peak value due to limitations in the cardiovascular and respiratory systems. As a result, a multitude of research was sparked that examined the different phases of oxygen consumption.

Oxygen consumption can be divided into three phases: oxygen intake, oxygen transport, and oxygen utilization, and the efficiency of each phase depends on a host of physiological systems within the body (Brooks, Fahey, and Baldwin, 2005). Oxygen intake is the actual breathing in of oxygen from the ambient environment into the lungs. Oxygen transport is the diffusion of the oxygen from the lungs into the blood, where it travels through the circulatory system to the site of the working muscle and is delivered via capillaries. Oxygen utilization is the muscle's ability to take the oxygen and use it to generate energy through the aerobic metabolic pathways. The rate at which these processes can occur during exercise depends largely on the capacity of the heart, lungs, and blood to transport the oxygen to the working muscle, as well as the muscle's ability to extract the oxygen for use in metabolism (Bassett and Howley, 1999).

The rate of oxygen consumption is governed by the Fick Equation, $VO_2 = Q \times (a\text{-}v)O_2diff$ (Mitchell and Blomquist, 1971). In this equation, Q represents cardiac output which is calculated by stroke volume (the amount of blood the heart ejects per beat) multiplied by the heart rate (number of times the heart beats per minute). Arterial-venous oxygen difference [$(a\text{-}v)O_2diff$] represents the difference between arterial and venous concentrations of oxygen, giving the amount of oxygen that is actually extracted and used by skeletal muscle. The rate of oxygen consumption is therefore dependent upon the development of the cardiovascular and pulmonary systems, and as a result, maximal oxygen consumption has become a key indicator of cardiovascular fitness (Bassett and Howley, 1999).

During exercise, the oxygen that is transported to the muscle is used through aerobic metabolism to generate energy that powers skeletal muscle contractions. These contractions allow the muscles to move in concert, giving the body locomotion at a level that meets the workload demand of a given intensity of exercise. As the workload of exercise increases, the energy demand to match this intensity also increases. As a result, oxygen consumption increases to meet the energy demand aerobically. Aerobic metabolism is the preferred method of energy production during exercise as it is more efficient, producing fewer by-products than anaerobic metabolism. At higher workloads of exercise a larger amount of oxygen is needed to produce energy aerobically, so the consumption of oxygen increases as the intensity of exercise increases (Skinner and

McClellan, 1980). This relationship was confirmed by research that examined the oxygen cost of running, completed by Bransford and Howley (1977). The researchers tested both trained and untrained subjects of both genders, and found that a linear relationship existed between an increase in running speed and an increase in oxygen consumption. The lowest correlation coefficient calculated for any individual tested was reported as $r = 0.98$ when comparing running speed and oxygen consumption. As a result, they reported that the relationship between exercise workload and oxygen consumption was linear, agreeing with the original data previously mentioned by Hill and Lupton (Bransford and Howley, 1977).

Maximal oxygen consumption has long been regarded as a major physiological parameter associated with success in endurance sports. As a result, the relationship between maximal oxygen consumption and success in athletics has been widely investigated. An examination of VO_{2max} in elite athletes was conducted using 133 individuals who composed the Swedish National Team (Saltin and Astrand, 1967). The researchers found very high average values for VO_{2max} in the athletes that were observed; the top 15 VO_{2max} values measured in males equaled 5.75 L/min while the top 10 VO_{2max} values measured in females equaled 3.6 L/min. An individual maximum of 6.17 L/min was also reported for one of the athletes, indicating a link between high values of oxygen consumption and performance at the elite level of athletics.

The body of literature on oxygen consumption and success in endurance sports has also focused closely on the relationship between oxygen consumption and long distance running performance. Multiple studies have confirmed a strong relationship between VO_{2max} and long distance running ability. Twenty-six well-trained distance runners (avg. VO_{2max} = 60.9 ml/kg/min) were measured for maximal oxygen consumption and also competed in three timed performances of 1 mile, 2 miles, and 6 miles. Measurements for VO_{2max} correlated strongly with running time in the three competitive events, producing r values of -0.84, -0.87, and -0.88 respectively (Foster, Costill, Daniels, and Fink, 1978). These findings were confirmed in other research studies as well, including an evaluation of seventy-eight well-trained distance runners with respect to their VO_{2max} and performance over races of 1, 2, 3, 6, 10, and 26.2 miles (Foster, 1983). VO_{2max} was again shown to correlate highly with running time (performance), producing correlation coefficients of -0.91, -0.92, -0.94, -0.96, -0.95, and -0.96 respectively for the increasing race distances.

As oxygen consumption has been widely examined with specific interest in the realm of endurance sports, the ability to quantify this value through exercise testing has become a point of significant interest.

Testing Protocols for the Evaluation of VO_{2max}

Throughout the body of literature on maximal oxygen consumption, many different testing methods and protocols have been developed and explored to quantify this variable of interest. Researchers have tested endurance athletes using many different methods of exercise, including running on a treadmill, riding on a cycle ergometer, and many other modes of exercise within a laboratory. These types of tests have also been developed to take place in the actual environment of competition, outside of the lab. Three main methods that are found to be most abundant in research include submaximal tests, field tests, and maximal tests (Heyward, 2006).

Submaximal tests to evaluate VO_{2max} have been developed to determine maximal oxygen consumption without requiring an individual to reach a maximal level of exertion. These tests use oxygen consumption at submaximal workloads to predict an individual's maximal oxygen consumption value. Submaximal tests are safer to use in unhealthy populations, as these individuals are typically not fit for a protocol that calls for a maximal level of exertion. Although this is not a direct measurement of maximal oxygen consumption, collecting data at a submaximal workload and extrapolating is a reasonably accurate way to estimate and individual's VO_{2max} (Heyward, 2006). Research has verified this point, specifically with using a cycle ergometer at low intensities to predict an individual's $VO2_{max}$ (Keren, Magazanik, and Epstein, 1980). Through testing fifteen recreational athletes, the researchers found that predicted VO_{2max} using the Astrand-Rhyming protocol (59.9 ml/kg/min) was only 6% lower than VO_{2max} measured using a maximal treadmill test (63.8 ml/kg/min). They concluded that this difference was small enough to sufficiently predict maximal oxygen consumption using a submaximal estimation.

Field tests to evaluate VO_{2max} have also been utilized in oxygen consumption research. These tests involve measuring an individual's maximal oxygen consumption in the actual environment in which they train and/or compete. Researchers typically will collect expired gas for retro-analysis to determine maximal oxygen consumption. The positives of these protocols are that they mimic an individual's actual competitive arena, increasing level of comfort and familiarity for an athlete since it is not occurring inside of a laboratory. A drawback is that an athlete may not be able to truly perform a maximal effort as the workload of exercise is not controlled by the researcher but is controlled by the subject themselves (Heyward, 2006). Field testing has been compared with laboratory testing, and it has been shown that no differences in VO_{2max} occur when similar protocols are used in both settings (Meyer, Welter, Scharhag, and Kindermann, 2003). Researchers had eighteen well-trained runners complete identical running protocols to maximal exertion on both an outdoor track and in a laboratory on a treadmill. The results showed no significant difference in oxygen consumption between the treadmill test (avg VO_{2max} = 63.5 ml/kg/min) and the field test (avg VO_{2max} = 63.3 ml/kg/min), validating the use of field testing to measure VO_{2max} in distance runners.

The most highly regarded and utilized method for measuring maximal oxygen consumption is the prescription of maximal exercise tests in a laboratory. These protocols use increasingly higher workloads of exercise to elicit a maximal effort from a subject; all the while respiratory gases are collected and analyzed simultaneously within the lab. There are many major benefits to these types of tests, as they are highly controllable by the researcher, eliminating many opportunities for error that may exist outside of the laboratory. Also, as these tests are controlled by the researcher, it is more likely that an individual may reach a true maximal effort where maximal oxygen consumption can be evaluated and measured at that specific point in time (Heyward, 2006).

During maximal exercise tests, researchers are able to measure and record a litany of physiological data that corresponds with progressively higher levels of exercise intensity. The most common variables that are evaluated during these tests are VO_{2max}, heart rate, RPE (rating of perceived exertion), and lactate. By collecting these variables, researchers are able to examine the step-by-step process that occurs physiologically as an individual moves from the onset of exercise to the cessation of a test when a maximal effort is achieved.

When using maximal exercise tests to evaluate the physical condition of endurance athletes, researchers can take the data that is collected and apply the findings to help improve and fine-tune training methodology for a given sport. For example, determining a distance runner's VO_{2max} and lactate threshold in the laboratory can allow the athlete to use these values to determine the intensity of training that they should perform at certain points during a training cycle and competitive season (Midgley, McNaughton, and Wilkinson, 2006).

Athletes and coaches have also used maximal exercise testing to determine the efficacy of training programs. By measuring VO_{2max} at the beginning, middle, and end of a training cycle, it becomes apparent if the training adaptations were significant enough to induce an increase in $VO_{2max,}$ and subsequently, and increase in performance (Midgley, McNaughton, and Wilkinson, 2006).

In long distance running, maximal oxygen consumption has been studied using the method of treadmill testing. To reach a maximal level of exertion, these protocols utilize changes in grade or speed to progressively raise the intensity of exercise over the duration of the test. Much research has been conducted on treadmill testing, including comparisons between protocols that manipulate grade, speed, and both grade and speed together to elicit a maximal exercise response from a subject.

Differences in VO_{2max} Measurements Using Varying Treadmill Protocols

Research comparing VO_{2max} measurements using different treadmill protocols has been frequent in oxygen consumption literature. Many studies have focused on comparing multiple protocols to validate methods of measuring VO_{2max} using treadmill testing.

A group of researchers tested fifty-one middle-aged men on four commonly prescribed maximal treadmill stress testing protocols, in order to evaluate and compare the effectiveness of using each protocol to measure cardiopulmonary function (Pollock, Bohannon, Cooper, Ayers, Ward, White, and Linnerud, 1976). The subjects were composed of twenty-two endurance trained athletes and twenty-nine sedentary individuals. All subjects completed four maximal tests: Balke, Bruce, Ellestad, and Modified Astrand protocols. These treadmill protocols each manipulated speed and grade in a different way to increase workload over the duration of the tests. By including a wide range of protocols, researchers were able to investigate the effect of differences in treadmill speed and grade and the effect on maximal oxygen consumption. The Balke protocol increased in grade from 0% while holding a constant speed of 3.3 mph. The Bruce protocol increased in both speed and grade per stage, at 3 minute intervals. The Ellestad protocol started at a grade similar to the Bruce protocol, but held grade constant and increased speed until the 10 minute mark; at this point the grade was increased from 10 to 15%, where it remained constant while speed was increased to raise the workload. The modified Astrand protocol held a constant speed between 5 and 8.5 mph while grade was increased.

The mean VO_{2max} values were obtained for each protocol using all subjects and compared statistically; no significant differences were found between all protocols, with the exception of a 2.4 ml/kg/min difference between the Balke (39.4 ± 5.9 ml/kg/min) and Astrand protocols (41.8 ± 6.7 ml/kg/min), ($p = .05$). The researchers deemed this difference to be of minimal physiological significance. These results indicated that many different treadmill protocols can elicit the same physiological response in maximal oxygen consumption.

A more recent study has examined the same issue of using multiple protocols to evaluate VO_{2max}, using both trained and untrained subjects (Kang, Chaloupka, Mastrangelo, Biren, and Roberston, 2001). This study examined 15 untrained men, 10 untrained women, and 12 trained subjects of both genders across three different protocols for $VO2_{max}$: Astrand, Bruce, and Costill/Fox. In the untrained subjects, no differences were found in maximal oxygen consumption across all three protocols. In trained subjects however, the Bruce protocol produced significantly lower values for VO_{2max} in comparison to the Astrand and Costill/Fox protocols. As the Astrand and Costill/Fox protocols rely on smaller increases in grade while using a constant running speed to manipulate workload, the researchers concluded that these two protocols were more effective at measuring VO_{2max} in trained individuals because the workload was more manageable over the duration of the test in comparison to the Bruce protocol. They supposed that the large jumps in gradient during the Bruce protocol may induce premature fatigue in trained athletes who are not accustomed to training on such gradients, confirming results of previous studies focused on treadmill testing specificity in trained subjects (Davies, et al. 1984; McConnell and Clark, 1988).

This idea of test specificity was explored in earlier years, as one study tested 10 distance runners on four treadmill protocols that had various speed combinations to judge the effect of different speeds on maximal oxygen consumption (McConnell and Clark, 1988). Protocols 1 and 2 had set speeds of 3.58 m/s, and increased in grade by 2.5%

every 1 and 2 minutes, respectively. Protocol 3 had a set speed of the subject's average daily training pace (3.89 ± 0.22 m/s), and increased in grade by 2.5% every minute. Protocol 4 had set speed of the subject's choice (3.53 ± 0.50 m/s), and increased in grade by 2.5% every minute. No significant differences were found in VO_{2max} between all four protocols (1.1% variance between means reported). The researchers concluded that all four tests could effectively determine VO_{2max} in distance runners, and also discovered that one minute stages were just as effective in eliciting VO_{2max} as two minute stages when manipulating grade. The fact that all four protocols are very similar to each other makes the continuity among VO_{2max} measurements an expected result.

Earlier research by Davies, et al tested 10 long distance runners (5 males, 5 females) on five different treadmill protocols to determine VO_{2max} (1984). The protocols used in this study were more varied than those featured in the work of McConnell and Clark (1988). Three of the protocols involved running at a steady speed of 12 km/hr for women and 14 km/hr for men, while increasing grade 1.5% every 1, 2, or 3 minutes. The fourth protocol involved starting at the same speeds of 12 km/hr and 14 km/hr for females and males, respectively, and increasing speed by 1 km/hr every minute. The fifth protocol involved starting at 10 km/hr on a non-motorized treadmill and increasing the speed by 2 km/hr every three minutes until exhaustion. Upon completion of the study, no significant differences were found across all five protocols with respect to VO_{2max}. From these results, the researchers concluded that all five protocols could be used with confidence to determine maximal oxygen uptake in trained individuals. While the protocols were obviously similar amongst themselves, the protocols used in this study were not compared to a standard treadmill testing protocol used across the literature, such as the Bruce protocol. As a result, it is not possible to confirm that these protocols elicited maximal oxygen consumption values that would be consistent with those produced by a standardized testing protocol. A more homogenous subject pool could have added more meaning to these results, as the subjects' specialties ranged from sprint events to the 1500m to very long distance training. It was also mentioned that a few of the female athletes were not very well-suited in terms of endurance performance.

The researchers made a final suggestion that the specificity of the protocol chosen should simulate the muscular movements involved in an individual's particular activity or sport, in order to provide a most meaningful assessment of maximal oxygen consumption. This idea confirms findings already reported in other areas of athletics, including cross-country skiers, rowers, and cyclists who all produced significantly higher values for VO_{2max} when tested on a sport-specific protocol in comparison to an uphill running protocol (Stromme, Ingjer, and Meen, 1977).

In order to further clarify the point of protocol specificity in treadmill testing, examination of horizontal vs. inclined protocols becomes necessary.

Differences in VO_{2max} Measurements Using Inclined and Horizontal Treadmill Protocols

To date, research comparing VO_{2max} measurements using inclined treadmill protocols with those obtained using horizontal treadmill protocols has not produced consistent results. The research that has been conducted has produced conflicting findings, primarily due to a wide range of subject populations that have been enlisted for investigation.

Initial research in this area used mostly untrained subjects, consistently reporting higher VO_{2max} measurements obtained using an inclined protocol in comparison to a horizontal protocol. Taylor et al found that an inclined protocol elicited higher VO_{2max} values than a horizontal protocol in non-runners (1955). This result was confirmed by Astrand and Saltin a few years later (1961). They tested three subjects on both inclined and horizontal protocols, recording higher VO_{2max} values during the inclined protocol for each subject. Saltin also confirmed these findings in later research; six untrained individuals were measured for VO_{2max} using maximal running on a horizontal treadmill and maximal running at an inclination of +3 degrees. Average VO_{2max} values were reported to be 7% higher when obtained using the inclined protocol (Hermansen and Saltin, 1969).

Comparing maximal oxygen consumption values between horizontal and inclined protocols has produced more equivocal results when trained subjects are enlisted for investigation. Research findings can be found that support multiple claims. Some research has found that inclined protocols produce higher VO_{2max} values than horizontal protocols. Other studies (although fewer) have indicated that horizontal protocols produce higher VO_{2max} values than inclined protocols. Finally, research in this area has also shown that there is no difference in VO_{2max} between horizontal and inclined protocols. These differences and potential reasons for disagreement are discussed below.

One early study in this area reported that horizontal protocols elicit VO_{2max} values that are equal to paired-mean VO_{2max} scores for an inclined protocol in trained runners (Sucec, 1974). This result was confirmed a few years later by an experiment that would become one of the most-cited works in this area of research.

This major research study examined the differences in VO_{2max} during horizontal and inclined treadmill running with matched intensity (Kasch, Wallace, Huhn, Krogh, and Hurl, 1976). The researchers tested 12 well-trained college males using a horizontal treadmill running protocol that featured one minute stages of increasing speed with a constant grade of 0% and an inclined treadmill running protocol that increased in grade at each stage while holding a constant speed, similar to the Costill/Fox protocol utilized in similar areas of research (Costill and Fox, 1969). Both protocols were matched for duration so that the average test time was similar for each protocol. The results showed no significant difference in mean VO_{2max} response between the inclined protocol (4.267 L/min) and the horizontal protocol (4.192 L/min). Average values for heart rate were also not significantly different between the inclined (190.4 bpm) and horizontal (188.9 bpm) protocols. The researchers concluded that the intensities of both the inclined and horizontal protocols were matched well enough to elicit similar VO_{2max} responses in well-trained college males (Kasch, Wallace, Huhn, Krogh, and Hurl, 1976).

Two studies focusing on training effect and treadmill testing have also examined the differences in measuring VO_{2max} using horizontal and inclined treadmill protocols (Freund, Allen, and Wilmore, 1986). The researchers tested twenty-two males who were previously untrained (ran fewer than 10 miles per week), using both inclined and horizontal treadmill protocols to establish baseline values for VO_{2max} prior to implementing a training program. The pre-training measurements of VO_{2max} were not significantly different between the inclined protocol (53.1 ± 4.0 ml/kg/min) and horizontal protocol (53.6 ± 3.9 ml/kg/min). The results of this initial testing were in disagreement with the general consensus of research that had been previously documented with untrained subjects, as all prior studies had reported higher VO_{2max} values for inclined protocols. After a twelve week training intervention where the subjects completed four weekly sessions of 35 minutes of running on inclined/hilly terrain between 65-85% of VO_{2max}, the subjects were retested on both protocols. The post-training measurements of VO_{2max} were significantly different between the protocols, as the inclined protocol produced a significantly higher average (59.0 ± 5.6 ml/kg/min) than the horizontal protocol (56.6 ± 4.5 ml/kg/min), ($p < .05$). These findings indicated that measurements in VO_{2max} could be different between horizontal and inclined protocols in trained subjects, disagreeing with the previously mentioned findings of Kasch, Wallace, Huhn, Krogh, and Hurl (1976). These findings also suggest that the specificity of the protocol to the type of training carried out by an athlete may affect measurements of $VO_{2max.}$ The researchers recommended that an individual's training terrain and modalities should be considered when choosing a treadmill test for performance testing (Freund, Allen, and Wilmore, 1986).

Allen, Freund, and Wilmore then conducted the same experiment, except for implementing a training protocol that used horizontal/flat terrain as opposed to inclined/hilly terrain (1986). Twenty-seven college-aged male subjects, of an untrained status, were tested in this study. No significant difference was found in VO_{2max} for pre-test measurements between the horizontal protocol (3.80 ±0.12 L/min) and the inclined protocol (3.95 ± 0.12 L/min), confirming the findings from their first experiment but again disagreeing with early research with untrained subjects. After a 12 week training intervention where the subjects exercised 4 times per week for 37 minutes on flat terrain, at an intensity of 65-85% VO_{2max}, they were re-tested using both protocols. A significant difference was found between protocols after the training intervention, as the inclined protocol elicited higher values for VO_{2max} (4.22 ± 0.12 L/min) than the horizontal protocol (4.07 ± 0.12 L/min). These findings agreed with their previous results, indicating that inclined protocols elicit higher average VO_{2max} values than horizontal protocols in trained subjects. The fact that the VO_{2max} values for the horizontal protocol did not significantly increase after the horizontal training intervention suggests that the specificity of the testing protocol is not of paramount importance in athletes who train on the flat ground. These findings disagree with their previous results achieved after an inclined training intervention (1986). It should be noted that the relatively short period of training intervention (12 weeks) may not have been sufficient time to induce specific adaptations that would allow success on one protocol over another. Evaluating this scenario in elite athletes who have been training specifically for very long periods of time may provide more meaningful information on the link between training specificity and performance on a similar treadmill protocol.

Researchers have attempted to explain why VO_{2max} values may be higher when testing with uphill protocols in comparison to horizontal protocols (Pokan, Schwaberger, Hofmann, Eber, Toplak, Gasser, Fruhwald, Pessenhofer, and Klein, 1995). Ten male subjects were tested on two different protocols; a constant grade protocol and an constant speed protocol. The constant grade protocol (CG) was an uphill protocol that remained at 5% while starting at 6 km/hr and increasing in speed by 2 km every 3 minutes. The constant speed protocol (CS) used a steady speed of 5 km/hr and started at 0% grade, increasing by 5% every 3 minutes. Maximal oxygen consumption values were 35% higher for the uphill (CS) protocol (62.6 ± 7.2 ml min) than the horizontal (CG) protocol

(46.2 ± 6.0 ml/kg/min), confirming the findings of many previous research works. The researchers also noticed that VO_2 leveled off during each test using the horizontal protocol, but similar activity was not observed during the tests using the uphill protocol. As a result, they concluded that VO_2 was limited in horizontal running, due to a mechanical or neuromuscular constraint on depth of breathing. This was confirmed by a "flattening" of ventilation that was observed on a plot of the data collected during the horizontal protocol tests. This may be something to consider when testing individuals on uphill and horizontal protocols, although it should be noted that the subjects used in this experiment were not specifically-trained runners or of an elite nature. This indicates the need for further experimentation in this area with an elite subject pool.

One study that disagrees with all of the previous results with trained subjects reported that a horizontal protocol elicited higher VO_{2max} values than an inclined protocol for well-trained runners (Wilson, Monego, Howard, and Thompson, 1979). This result is likely attributable to the fact that the 10 subjects that were tested were all specifically-trained for the one-mile event on the track. As these athletes trained specifically on the flat surface in preparation for their event, it is likely that they developed physiological qualities that left them better suited for a horizontal testing protocol.

The wide range of subjects enlisted for research comparing horizontal and inclined treadmill protocols has led to inconsistent results across the body of literature. While research has focused somewhat on trained subjects, it has yet to focus on the truly elite athlete in long distance running, prompting the need for further investigation on this specific population. Also, previous research has indicated some importance on the specificity of testing protocol to match an athlete's type of training, although results have not been consistent. Further investigation into this topic at the elite distance running level is necessary as well to establish guidelines for maximal oxygen consumption testing.

Differences in Muscle Fiber Type and the Recruitment of Muscle Mass in Horizontal vs. Uphill Running

In long distance runners, differences in skeletal muscle fiber type distribution, recruitment of fiber type, and the amount of muscle activation during exercise may have implications in explaining any differences in oxygen consumption observed in horizontal and uphill running.

Type I fibers are small in size, and are used to produce low amounts of force for long periods of time. These slow twitch fibers rely on triglycerides as a fuel source, and are said to be aerobic in nature. Type IIa fibers are medium in size, and generate larger amounts of force than the slow twitch fibers, but for a lesser amount of time. Type IIa fibers are more anaerobic in nature than the slow twitch fibers, and rely on glycogen and creatine phosphate as fueling sources. Type IIb fibers are the largest in size, and are the most anaerobic in nature. These fibers rely on creatine phosphate stores to generate large amounts of force over very short periods of time (Brooks, Fahey, and Baldwin, 2005).

During progressive exercise, the recruitment of skeletal muscle fiber type changes as the intensity of exercise increases (Essen, 1977). At low intensities of running, the slow twitch (Type I) fibers are recruited to supply the force required for locomotion. As the intensity increases, the recruitment of fast-twitch fibers (Type IIa) begins to supplement the Type I fibers to meet the demand or exercise. As the intensity of exercise reaches a near maximum, the Type IIb fibers are recruited on top of the Type I and Type IIa fibers to support a maximal exercise effort. The literature has consistently reported that fiber type composition can vary greatly at the individual level, and can also be altered through exercise training. As a result, the specific fiber type composition of an athlete can play a large role in their success or failure in certain athletic events. For athletes who are runners, a great example of this difference can be seen through comparing the fiber type compositions of athletes who are successful in the sprints, middle-distances, and long distance races (Costill, Daniels, Evans, Fink, Krahenbuhl and Saltin, 1976).

Fiber type composition in endurance athletes, specifically in long distance runners, has been a topic of much interest. Initial research examining fiber type composition in elite track athletes found differences in the percentage of slow-twitch fibers between individuals who specialized in different events (Costill, 1976). Muscle biopsies were taken from the gastrocnemius of seven male middle-distance runners and five male distance runners. Long-distance runners were found to have a higher percentage of slow-twitch fibers (69.4%) in comparison to the middle-distance runners (51.9%). These findings have since been confirmed by more extensive studies.

An article published in 1977 examined the metabolism and fiber types of skeletal muscle in both endurance runners and untrained subjects (Saltin, Henriksson, Nygaard, Andersen, and Jansson). These researchers reported varying fiber type composition among cross-country runners (n=8), track runners (n=10), and sedentary individuals (n=70). Total fiber composition was divided between four categories: slow twitch (Type I), fast twitch (Type IIa and Type IIb), and unclassified. Cross country runners had a higher percentage of Type I fibers (67.1 ± 8.7%) than track runners (61.4 ± 4.6%) and untrained subjects (54.0 ± 12.2%). Track runners had a higher percentage of Type IIa fibers (36.9 ± 5.6%) than untrained subjects (32.3 ± 9.1%) and cross country runners (28.9 ± 8.9%). Lastly, Type IIb fibers were highest in the untrained population (13.0 ± 7.6%) when compared to cross country runners (1.9 ± 4.3%) and track runners (0.5 ± 0.8%). The results between cross country runners and track runners are not too surprising, as cross country athletes expressed a larger proportion of aerobic (Type I) fibers in comparison to the track runners, who expressed a larger proportion of anaerobic (Type-IIa) fibers than cross country runners. These findings are expected when considering the physical demands of racing cross country and track competitions. The nature of cross country races tends to be more controlled in terms of pace, as the runners navigate hills and varying terrain. The slower pace keeps the event more aerobic in nature in terms of energy production, which matches well with their aerobically-favored fiber type distribution. As track races take place on flat terrain, the paces of running tend to be faster and thus the intensity of the competitions is higher. As a result, a larger percentage of energy contribution comes from anaerobic sources, corresponding well to the higher amount of Type-IIa fibers seen in these athletes.

The differences seen in fiber type distribution between hilly-terrain runners and flat-terrain runners may have implications on the type of treadmill test they are best suited for in maximal stress testing. It is possible that an individual will perform better on a treadmill test that they are best suited for in terms of physiological profile, such as the predominance of muscle fiber-type distribution. This point indicates the need to evaluate this area of research further.

Differences in muscle activation have been observed in studies comparing both horizontal and uphill running. A group of researchers studied the difference in lower extremity muscle activation between flat and uphill running, as well as differences in peak oxygen deficit and maximal oxygen consumption (Sloninger, Cureton, Prior, and Evans, 1997). This study investigated the differences in muscle activation between horizontal and uphill running in twelve young women. The amount of muscle activation was quantified using magnetic resonance images that indicated to what extent the muscles of the lower body were being used. Subjects completed two short-duration (2.0 – 3.9 min) supra-maximal running tests to exhaustion, with workload set at 115% of VO_{2max}. The treadmill was set at 0% grade during the horizontal test and 10% grade during the uphill test. VO_{2peak}, peak oxygen debt, and activation of muscle groups in the lower extremities were evaluated and quantified. The mean percentage of muscle mass recruited in the lower extremity was significantly higher ($P < 0.05$) in the uphill running test (73.1 ± 7.4%) in comparison to the horizontal running test (67.0 ± 8.3%). These findings were also accompanied by a significantly ($P < 0.05$) larger mean VO_{2peak} during uphill running (2.90 ± 0.50 L/min) than horizontal running (2.82 ± 0.50 L/min), a difference of 3%. The mean peak oxygen deficit was also significantly larger ($P < 0.05$) for uphill running (49 ± 6 ml/kg/min) in comparison to horizontal running (41 ± 7 ml/kg/min), a difference of 21%. From these results, the researchers concluded that the larger values for peak oxygen debt and oxygen consumption that are observed during uphill running in comparison to horizontal running can be contributed to the larger amount of muscle mass being activated to run uphill at the same workload. As a larger amount of muscle mass is used to run uphill, this could have implications for other physiological conditions observed during running over different terrain, including lactate production and fatigue. If lactate production and fatigue are not consistent between uphill and horiztonal test protocols, this could be reflected in differences between VO_{2max} measurements collected using various tests. As a result, this area of study requires greater exploration.

The Applicability of VO_{2max} Testing on Development of Training Thresholds

One benefit of testing a long distance runner for maximal oxygen consumption is that this value can be used to create and prescribe training programs for improvement in running performance (Midgley, McNaughton, and Jones, 2007). The manipulation of training intensity (as a percentage of $VO_{2max)}$ has been closely examined with the resulting changes in VO_{2max}, and the results have varied greatly. Different training interventions of running at varying intensities between 70% to 132% of VO_{2max} have been reported to increase maximal oxygen consumption (Billat, Sirvent, and Lepretre, 2004; Billat, Demarle, and Paiva, 2002; Franch, Maden, and Djurhuus, 1998).

Training at intensities well below VO_{2max} have been shown to significantly increase maximal oxygen consumption, as Billat et al reported a significant increase in VO_{2max} after incorporating training sessions of running between 70-85% VO_{2max} (2004). Other researchers have suggested that runners should train at an intensity that elicits between 90-100% of VO_{2max} (Wenger and Bell, 1986). This notion has been supported by experimenting with well-trained distance runners, as the literature has reported a 5.4% increase in VO_{2max} ($p < .05$) when including training bouts of running at 90-100% of VO_{2max}, even when total volume of training was reduced by 10% (Billat, Demarle, and Paiva, 2002). Other research has indicated that supra-maximal running efforts that are above VO_{2max} (106% and 132%) have also increased maximal oxygen consumption in distance runners (Franch, Maden, and Djurhuus, 1998). These researchers reported gains in VO_{2max} when they had subjects include 15 second intervals at the aforementioned intensities, accompanied by an equal period of rest between repetitions. The mixture of training intensities that have been reported to increase VO_{2max} indicates that there are many viable training methods to improve oxygen consumption and thus, running performance. No matter which training method a coach employs, the advantage of having an accurate measurement of VO_{2max} is clear.

Many coaches have also used the method of improving anaerobic threshold as an important training tool. Researchers have confirmed this training methodology as effective in improving endurance performance, as increases in the anaerobic threshold have been connected with increases in endurance performance throughout the literature (Hawley, Myburgh, and Noakes, 1997; Billat, 1996; MacDougall, 1977; Tanaka, 1990). Many coaches prescribe training sessions that include running at paces that elicit the percent of maximal oxygen consumption ($\%VO_{2max}$) that corresponds with the onset of blood lactate, or anaerobic threshold (Midgley, McNaughton, and Jones, 2007). As a result, it is useful to have an accurate measurement of the $\%VO_{2max}$ at which the anaerobic threshold occurs in long distance runners.

Many techniques exist to measure the anaerobic threshold, but the one of most interest for coaches is the determination of the ventilatory threshold. This method of determining the anaerobic threshold is much less invasive than others which typically require the collection of blood samples, making it a more desirable option for many athletes (Heyward, 2006). The ventilatory threshold is determined by analyzing both oxygen consumption (VO_2) and carbon dioxide production (VCO_2) data collected during a maximal treadmill test. These values are plotted and examined for a non-linear increase in VCO_2; the "break-away" point is identified where VCO_2 increases sharply while VO_2 begins to flatten out. This point represents the addition of anaerobic energy production to meet the demand of exercise, and as such is a ventilatory representation of the anaerobic threshold (Khaled, Egred, Alahmar, and Wright, 2007). Estimating the anaerobic threshold through this method of determining the ventilatory threshold has been validated in the literature (Wasserman, Whipp, Koyal, and Beaver, 1973; Casaburi, Whipp, Wasserman, Beaver, and Koyal, 1977). As a result, the ability to accurately measure the ventilatory threshold as a percentage of VO_{2max} in long distance runners is important and deserves further examination.

Summary

Maximal oxygen consumption, or VO_{2max}, is the maximal amount of oxygen that an individual can bring in and utilize during exercise to create energy aerobically. VO_{2max} has been heavily investigated throughout the field exercise physiology; much of the research has focused on the connection between VO_{2max} and success in endurance sports, including long distance running.

Many different types of testing procedures exist to determine maximal oxygen consumption; submaximal tests, field tests, and maximal tests have all been validated as approved methods for determining VO_{2max} in a variety of populations. Maximal testing using a treadmill has been a popular choice amongst researchers who have studied long distance runners, and the protocols that have emerged to determine VO_{2max} in this population have been numerous.

Specific focus has been paid to the extent of which manipulating speed and grade of the treadmill can affect the determination of $VO_{2max.}$ The wide range of subjects enlisted for research comparing horizontal and inclined treadmill protocols has led to inconsistent results across the body of literature. While research has focused somewhat on trained subjects, it has yet to focus on the truly elite athlete in long distance running, prompting the need for further investigation on this specific population.

Also, previous research has indicated some importance on the specificity of testing protocol to match an athlete's type of training, although results have not been consistent. Further investigation into this topic at the elite distance running level is necessary as well to establish guidelines for maximal oxygen consumption testing.

CHAPTER III

METHODS

Subjects

Sixteen high school, college, and post-collegiate runners of unspecified race or ethnicity, ages 18-30 were recruited to participate in this study. All subjects were long distance runners who had been training at a minimum volume of 50 miles per week for at least 6 months prior to enrolling in the study. Subjects must have been healthy (be classified as low risk individuals for participation in maximal exercise testing based on the guidelines set forth by the American College of Sports Medicine – ACSM) and free of any orthopedic injury that precluded successful completion of the requirements of the study. An initial health screening was performed to ensure eligibility for participation in the study, including a physical examination and administration of a medical history questionnaire and the Par-Q (Physical Activity Readiness Questionnaire).

Instrumentation

Eligibility for participation in the study was determined through physical examination, administration of medical history questionnaire, and administration of the Par-Q (Physical Activity Readiness Questionnaire) (Appendix I). Training status for the past six months was assessed using the training history questionnaire (Appendix II). Preparation for each testing session was governed by the pre-testing guidelines (Appendix III). Sleeping habits, dietary habits, and fatigue levels were assessed using the pre-trial questionnaire (Appendices IV and V). Height and weight were measured using a stature meter (Perspective Enterprises, Portage, MI, USA) and a Detecto 2381 balance beam scale (Detecto, Webb City, MO, USA) respectively. Hydration status was quantified by analyzing a urine sample by the specific gravity method using a refractometer (TS Meter, American Optical Corp., Keene, NH, USA). Heart rate was monitored with a Pacer model of a Polar heart rate monitor to measure heart rate during each testing trial (Polar, Lake Success, NY, USA). Resting blood pressure was assessed using an ADC 922 series aneroid sphygmomanometer (Hauppage, NY) and a Littmann stethoscope (St. Paul, MN). Each testing trial was conducted using a treadmill (Quinton, Medtrack ST65, Bothell, WA). Oxygen consumption and respiratory gas exchange was analyzed using a Parvo Medics TrueMax® 2400 Metabolic system (Parvo Medics, Salt Lake City, UT, USA). The rating of perceived exertion during the testing trials was quantified using the Borg 6-20 scale (Borg, 1970). Blood lactate analysis was performed using a hand-held Lactate Plus blood lactate analyzer (Sports Resource Group, Hawthorne, NY).

General Procedures

The study was a randomized, counter-balanced design where subjects served as their own controls. The first eight participants were randomized to perform either the speed only maximal oxygen consumption test ($SOVO_{2max}$) or the constant speed with variable grade maximal oxygen consumption test ($GOVO_{2max}$) during Trial One and then the other test in a subsequent testing trial (Trial Two). The last eight subjects were then allocated in a manner to counterbalance the trials by performing the reverse order of tests that were performed by the first eight subjects in the study.

The experiment consisted of three visits to the Applied Physiology Lab (APL) or Integrative Exercise Oncology Lab (IEOL) on separate days; all were completed within a span of two weeks. After potential subjects were identified through contact with coaches and athletic administrators from athletic organizations, interested subjects were invited to an initial visit (first visit) to the laboratory to receive further information about the study, to be further screened for participation eligibility, and to participate in a familiarization session. Prior to reporting to the laboratory, potential subjects were given instructions on what would happen during the familiarization trial. The first visit (Familiarization trial) was used to further screen subjects for participation in the study (complete a physical examination and the Par-Q questionnaire), to give further and detail information regarding the study protocol and requirements, to obtain a signed consent form approved by the UNC Chapel Hill IRB, and to familiarize subjects to the equipment that was used in the study. Subjects answered a training history questionnaire to ensure their qualification for the study. The familiarization with equipment was achieved through completing the Bruce maximal oxygen consumption test protocol on the laboratory treadmill and metabolic station that was used during data collection. The second and third visits (Trials 1 and 2) were used to complete either the $SOVO_{2max}$ or $GOVO_{2max}$ protocol on a treadmill.

Prior to each data collection trial, subjects were given a questionnaire regarding level of fatigue, sleep habits, and dietary habits. Also, each subject was weighed and provided a urine sample that was analyzed using the specific gravity method to ensure adequate hydration status. The sequence of study events is summarized in Table 1:

Table 1. Summary of Sequence of Study Events

1. Recruitment of Subjects	2. Visit 1 (Familiarization Trial)	3. Visit 2 (Trial 1)	4. Visit 3 (Trial 2)
a) Contact coaches and administrators to ask for permission to approach their runners; b) Approach potential subjects to introduce study c) Give information about Visit 1 to the APL/IEOL to subjects interested in participating in the study.	a) Subjects will report to the laboratory for further screening for the determination of participation eligibility and to receive detailed information of study protocol; b) Subjects will be asked to sign an informed consent form; c) Subjects will complete a physical examination as well as be asked to fill out a Par-Q form; d) Subjects will participate in a familiarization session of testing equipment by completing the Bruce maximal oxygen consumption protocol. e) Subjects will schedule Visit 2 with PI.	a) Subjects will be given a brief questionnaire orally regarding timing of last meal, sleep patterns, and qualitative level of fatigue; b) Subjects will be weighed and provide a urine specimen for the analysis of hydration; c) Subjects will participate in either the $SOVO_{2max}$ or the $GOVO_{2max}$ maximal oxygen consumption tests; d) Subjects will schedule Visit 3 with PI.	a) Subjects will be given a brief questionnaire orally regarding timing of last meal, sleep patterns, and qualitative level of fatigue; b) Subjects will be weighed and provide a urine for the analysis of hydration; c) Subjects will be assigned to participate in the other maximal oxygen consumption test.

First Visit: FAMILIARIZATION TRIAL

During the familiarization trial, subjects were further screened for participation in the study through physical examination performed by a research team member medically trained to perform physical examinations, and administration of the Par-Q (Physical Activity Readiness Questionnaire) that was given during the physical examination (PAR-

Q; Thomas, et al., 1992) (see Appendix I). During the physical examination, subjects were assessed for resting heart rate, blood pressure, asked to answer a medical history questionnaire, and underwent a resting electrocardiogram. Subjects deemed eligible to participate were then asked to sign the informed consent form. After the conclusion of the physical, baseline height and weight was assessed. The Baseline Measures/Training History Questionnaire was then administered to the subject to assess their training history (Appendix II). Average training volume for the past six months, the subject's opinion of their running strengths, and injury history were recorded.

Subjects were then fitted for the mouthpiece and helmet that was to be used during the measurement of oxygen consumption in both testing trials (Trial 1 and 2) until they were comfortable with wearing it. Subjects then experienced a simulation of a maximal oxygen consumption test protocol to complete the familiarization session. To do this, each subject completed the Bruce Protocol, a maximal exercise test that uses increases in speed and grade to elicit a maximal effort within each subject (Heyward, 2006). The goal of completing the Bruce Protocol was to ensure that each subject had experience with changes in speed and grade while running on the treadmill, comfort with the mouthpiece and helmet, and familiarity with the subsequent experimental protocols that were to be used in the study. Upon the completion of the familiarization trial, subjects were then scheduled for test trials 1 and 2 and were given pre-testing guidelines to be followed strictly before reporting to the laboratory for testing (see Appendix III). The entire study protocol occurred within 14 days from the time of completion of the familiarization trial to completion of the last testing trial.

Second Visit: TRIAL ONE

On the second visit to the laboratory, subjects were given a brief questionnaire (Pre Trial Questionnaire – Trial 1) to assess fatigue, sleeping patterns, and dietary patterns to ensure consistency between testing trials (see Appendix IV). A similar questionnaire assessing fatigue, sleeping patterns, and dietary patterns (Pre Trial Questionnaire – Trial 2) was administered on the third visit, prior to Trial 2 (see Appendix V) with the only difference being that a question asking what protocol the athletes liked the most was asked to each subject at the end of Trial 2. Subjects were then weighed and provided a urine specimen that was collected in a sterile plastic container for the analysis of hydration, performed using the specific gravity method with an optical densitometer. Two drops of urine was placed on the densitometer plate reader. The densitometer was then held up to a light and a reading was taken by viewing the sample from the densitometer eye piece. If it was determined that the athlete was not properly hydrated, the testing session was rescheduled for the following day.

After subjects were cleared for testing, they were fitted with a heart rate monitor and instructed to lie supine in a resting position for 5 minutes. At the end of this period, the subject's resting heart rate and blood pressure was recorded. The subject was then fitted with the mouthpiece and helmet to be used and was guided to the treadmill. The subject was given a 5 minute warm-up on the treadmill at 4 miles per hour, as well as light stretching prior to beginning the maximal exercise test.

At the end of the warm up, the exercise test began (Trial One). The $SOVO_{2max}$ or $GOVO_{2max}$ protocol was completed by the subject depending on which test was assigned first in the experimental order during the randomization process. Half of the participants completed the $SOVO_{2max}$ protocol first, while half performed the $GOVO_{2max}$ protocol first.

The $SOVO_{2max}$ protocol consisted of 1 minute stages that began at a speed of 5.0 mph for both male and female subjects. For males, this speed increased 1.0 mph per minute until reaching 11.0 mph. Beyond this stage, the speed increased in increments of 0.5 mph per minute until the subject reached maximal exertion. The final stage of this protocol called for a speed of 14.5 mph. For the females, the protocol increased 1.0 mph per minute until 8.0, where increases in speed were made in 0.5 mph/min increments thereafter until the subject reached exhaustion. The final stage of this protocol reached 12.5 mph. This protocol is outlined in Table 2. The subject's oxygen uptake (VO_2), heart rate, and Rating of Perceived Exertion (RPE) were recorded at the end of each stage. These parameters were also measured at the moment in which the subject called for the cessation of the test, reaching a maximal effort.

Gender differences were taken into consideration for the design of both the speed-only protocol ($SOVO_{2max}$) and grade-only protocol ($GOVO_{2max}$). High level male runners are able to reach higher speeds of running during testing than female runners. As a result, the female protocols were designed to start at a slower speed allowing for consistent test duration between genders. Also, within gender, the design of these protocols ($SOVO_{2max}$ and $GOVO_{2max}$) allows for the achievement of similar oxygen consumption values at each stage so true comparisons can be made between testing protocols.

Table 2. Speed-Only Protocol.

Stage (1 minute intervals)	Speed (mph) **Male**	Speed (mph) **Female**
1	5.0	5.0
2	6.0	6.0
3	7.0	7.0
4	8.0	7.5
5	9.0	8.0
6	10.0	8.5
7	11.0	9.0
8	11.5	9.5
9	12.0	10.0
10	12.5	10.5
11	13.0	11.0
12	13.5	11.5
13	14.0	12.0
14	14.5	12.5

The grade-only protocol consisted of 1 minute stages that began at a speed of 6.0 for males and 5.0 for females. The speed increased by 1.0 mph per minute until reaching a speed of 8.0 for males and 7.0 for females. The first 3 stages served as an extended warm-up period for the subject. At this point, the speed was held constant for the duration of the test and the grade of the treadmill was manipulated. Starting at the 4th stage, the grade of the treadmill increased by 2% every minute until the subject reached maximal effort. This protocol is outlined below in Table 3. The subject's oxygen uptake (VO_2) and VCO_2 were recorded every 15 seconds during the test. Measurements for heart rate and RPE were recorded at the end of each stage. These parameters were also be measured at the moment in which the subject called for the cessation of the test, reaching a maximal effort. RPE, ventilation, and RER data was collected as exploratory variables that may help interpretation of study results.

Table 3. Grade-Only Protocol.

Stage (1 min intervals)	Grade (%)	Speed (mph) – **Male**	Speed (mph) - **Female**
1	0	6.0	5.0
2	0	7.0	6.0
3	0	8.0	7.0
4	2	8.0	7.0
5	4	8.0	7.0
6	6	8.0	7.0
7	8	8.0	7.0
8	10	8.0	7.0
9	12	8.0	7.0
10	14	8.0	7.0
11	16	8.0	7.0
12	18	8.0	7.0
13	20	8.0	7.0
14	22	8.0	7.0

When subjects signaled for the end of the test, the protocol immediately stopped and the treadmill slowed to a relaxed walking pace to allow subjects to cool down. Three minutes after the cessation of the test, the subject sat in a chair and gave a finger-prick blood sample for lactate analysis. Lactate values were collected as an exploratory variable that may help interpretation of study results. Lactate analysis was performed using a handheld lactate plus blood lactate analyzer (Lactate-Plus, Sports Resource Group, Hawthorne, NY). Blood lactate was collected complying with standardized sampling following the described protocol below:

a) Subjects were asked to sit with hand with the palm-side up on a stable object (e.g. the arm of the chair) prior to exercising and again post exercise. The fourth or fifth fingertip was selected as these are likely to have fewer calluses on them.

b) Finger was cleaned with an alcohol swab. After disinfected, all attempts were made to not contaminate the area through touching it. If this occurred, the area was cleaned again.

c) While holding the subject's finger with one hand, the autolancet was placed with the other hand against the fingertip and the release button was pressed. Using a gauze pad, the subject's fingertip was squeezed and the first drops of blood were wiped off.

d) The following drop of blood was placed in the analyzer strip of the portable lactate analyzer for analysis.

e) After analysis, the autolancet needle, gauze pads, and anything else that touched blood was disposed into a sharps container.

The following criteria was used to determine if a maximal effort was obtained during each maximal oxygen consumption test:

1) No change in VO_2 (change < 2.1 ml/kg/min) with increase in exercise intensity
2) Heart rate within 10 bpm of age-predicted MHR
3) RPE $\geq$ 18
4) RER $\geq$ 1.10
5) Blood lactate above 8.0 mmol/L 3 minutes after test completion

Achieving a minimum of four of the criteria above defined if a maximal effort was achieved.

After subjects cooled down adequately and provided the finger-prick blood sample, the third visit was scheduled at a time to conform to the two-week time period provided to collect all data for that specific subject. All arrangements were made to schedule the session at a similar time of day within a window of 2 hours between the time of Trial One to control for circadian variations that could influence test results.

Visit Three: TRIAL TWO

For the third visit to the laboratory, the subjects followed the exact procedure from trial one in an identical manner. The $SOVO_{2max}$ or $GOVO_{2max}$ protocol was completed by subjects depending on the order determined by the randomization process.

Statistical Analyses

All data was gathered and entered into an electronic database for analysis. Descriptive statistics were presented in the form of means and standard deviations. All data was analyzed on SPSS version 18.0 for Windows, a statistical software program. All values for VO_{2max} and % VO_{2max} were reported as mean ± SD for each protocol. An alpha level of 0.05 was used for all analyses.

Each hypothesis was analyzed as follows:

Hypothesis 1: There will be no significant difference in maximal oxygen consumption (VO_{2max}) between the $SOVO_{2max}$ and $GOVO_{2max}$ treadmill testing protocols.

Hypothesis one was analyzed using a dependent samples t-test where the dependent variable the mean VO_{2max} of each test (VO_{2max} = highest VO_2 value attained during $SOVO_{2max}$ and $GOVO_{2max}$ protocols) will be used for comparison.

Hypothesis 2: There will be no significant difference in the %VO_{2max} at which the ventilatory threshold occurs between the $SOVO_{2max}$ and $GOVO_{2max}$ protocols.

Hypothesis two was analyzed using a dependent samples t-test where the mean percentage of VO_{2max} where the ventilatory threshold is attained during the $SOVO_{2max}$ and $GOVO_{2max}$ protocol will be used for comparison.

CHAPTER IV

RESULTS

The primary purpose of this study was to compare VO_{2max} values that were obtained using two different VO_{2max} graded treadmill tests; a horizontal (increment in speed only) protocol ($SOVO_{2max}$) and inclined (constant speed with increment in grade only) protocol ($GOVO_{2max}$). The secondary purpose was to examine if the ventilatory threshold attained during these tests occurred at the same proportion of VO_{2max} (% VO_{2max} @ VT).

Subjects

Anthropometric characteristics of subjects (n=16) are reported in Table 4 (Mean ±SD):

Table 4. Anthropometric Characteristics of Subjects.

Height (cm)	**Body Mass (kg)**	**Age (yr)**
175.2 ± 6.2	66.4 ± 5.6	23.4 ± 3.0

Physiological characteristics of subjects (n=16) are reported in Table 5 (Mean ±SD):

Table 5. Physiological Results of Subjects.

	$SOVO_{2max}$	$GOVO_{2max}$	Bruce
VO_{2max} (ml/kg/min)	71.2 ± 6.7*	76.1 ± 6.4*	75.3 ± 6.9
%VO_{2max} @ VT	77.2 ± 7.1	77.5 ± 5.7	75.4 ± 6.8
VO_{2max} @ VT (ml/kg/min)	55.2 ± 8.3	59.2 ± 8.1	56.7 ± 8.5
$^{+}$Lactate (mmol/L)	10.4 ± 2.5	12.1 ± 1.9	---
$^{++}V_E$ (L/min)	154.7 ± 19.1	171.0 ± 16.2	160.8 ± 21.4
$^{+++}$RER	1.19 ± 0.09	1.17 ± 0.07	1.23 ± 0.06
Max HR (bpm)	184.6 ± 8.4	185.6 ± 7.3	184.6 ± 6.5

$^{+}$Lactate values obtained 3 minutes after conclusion of VO_{2max} test. $^{++}$Maximal ventilation attained during VO_{2max} test. $^{+++}$Maximal Respiratory Exchange Ratio (RER) attained during VO_{2max} test. *Signficant difference at ($p < .001$).

Eleven subjects reported to be better suited for running and competing over hilly terrain, while five subjects reported to be better at track running on flat terrain. This preference in running ability did not show any differences between the treadmill protocols, as all subjects recorded higher values for VO_{2max} on the $GOVO_{2max}$ protocol. All subjects reported that they preferred the $GOVO_{2max}$ protocol over the $SOVO_{2max}$ protocol at the conclusion of the study. All subjects reached a maximal effort in all tests conducted, per the criteria set for the study.

Hypothesis 1

Hypothesis 1, there will be no significant difference in maximal oxygen consumption (VO_{2max}) between the $SOVO_{2max}$ and $GOVO_{2max}$ treadmill testing protocols, was analyzed using a dependent-samples t-test. The mean VO_{2max} values attained during the $SOVO_{2max}$ and $GOVO_{2max}$ protocols were used in the analysis. A significant difference ($p < .001$) was found between SOVO VO_{2max} (71.2 ± 6.7 ml/kg/min) and GOVO VO_{2max} (76.1 ± 6.4 ml/kg/min).

Hypothesis 2

Hypothesis 2, there will be no significant difference in the %VO_{2max} at which the ventilatory threshold occurs between the $SOVO_{2max}$ and $GOVO_{2max}$ protocols, was analyzed using a dependent-samples t-test. The mean percentages of VO_{2max} where the ventilatory threshold was attained during the $SOVO_{2max}$ and $GOVO_{2max}$ protocols were used in the analysis. No significant difference ($p = .825$) was found between %VO_{2max} at ventilatory threshold between $SOVO_{2max}$ (77.2 ± 7.1 %) and $GOVO_{2max}$ (77.5 ± 5.7 %) testing protocols.

CHAPTER V

DISCUSSION

Maximal oxygen consumption has been a key variable of interest for athletes, coaches, and researchers for quite some time. The close connection between VO_{2max} and performance in long distance running has led to a wide array of research on this topic, all with the goal of improving performance. The interest in improving performance in long distance runners was also the major impetus for performing this study. The main aim of this study was to provide coaches and athletes with a clearer picture in terms of the selection of treadmill protocol when using physiological testing to determine appropriate training intensities. Two novel treadmill protocols were developed to test the effects of speed and grade on the determination of VO_{2max} in high level runners. The design of the two protocols isolated the variables of treadmill speed and treadmill grade, allowing a close examination of the effects of these specific variables on the determination of maximal oxygen consumption. A secondary purpose was to compare the determination of ventilatory threshold in high level runners when tested on protocols that increased in either speed or grade.

Maximal Oxygen Consumption

When compared between the protocols, VO_{2max} was found to be significantly higher when measured during the $GOVO_{2max}$ protocol. This result agrees with findings previously reported in the literature with sub-elite level athletes (Hermansen and Saltin, 1969; Freund, Allen, and Wilmore, 1986; Kasch, Wallace, Huhn, Krogh, and Hurl, 1976). It was considered that high-level athletes may not produce the same VO_{2max} values between different tests, given the fact that they are very specifically trained over a long period of time. If an athlete trains exclusively on hilly terrain and considers themselves more suited for cross country running, it may be possible that physiological adaptations gained from training in this manner would support better performance on an uphill ($GOVO_{2max}$) protocol in favor of a horizontal ($SOVO_{2max}$) protocol. The same was considered for athletes who favored training on flat terrain and considered themselves more track-oriented athletes. As the speed of training is typically faster when training on flat surfaces as opposed to over undulating terrain, it was expected that these athletes may be suited better for performance on the SOVO protocol in favor of the GOVO protocol as they would be most comfortable with the increasing speeds of the flat protocol.

The results of the current study, however, do not support better performance on a VO_{2max} test that is similar in design with an athlete's training specificity. Every athlete tested exhibited higher VO_{2max} values on the $GOVO_{2max}$ protocol, even those that reported that they were track athletes and favored running on the flat surfaces. This result agrees with previous research that found that athletes who trained at equal intensities on an exclusively flat surface and an exclusively hilly terrain both produced higher VO_{2max} values on an uphill protocol (Freund, Allen, and Wilmore, 1986). The training intervention in this previous study was only 12 weeks long and was implemented in a group of previously untrained individuals, and so it was hoped that different results may appear in elite distance runners who train much more extensively over many years.

The current results do not agree with one of the only studies previously performed that examined this topic in high level runners (Wilson, Monego, Howard, and Thompson, 1979). They reported that athletes who specifically trained for the one-mile event, a speed event in terms of distance running on the track, produced higher VO_{2max} values on a horizontal protocol instead of an uphill protocol. This result is not supported by these new findings, as the track athletes still produced higher VO_{2max} values on the GOVO protocol although they were specifically trained for the flat, speed events.

Evaluating the findings of the current study helps support the connection between running uphill and higher maximal oxygen consumption values. When running uphill, a larger amount of muscle mass is recruited to facilitate movement up an incline in comparison to running flat. When comparing the $GOVO_{2max}$ with the Bruce protocol, both of which have a large uphill component, VO_{2max} values were not significantly different and were separated by an approximate difference of only 1 ml/kg/min. However, comparison of the $SOVO_{2max}$ protocol with the Bruce protocol showed a large difference of nearly 4 ml/kg/min in favor of the Bruce producing larger VO_{2max} values. This is consistent with the difference seen between the $GOVO_{2max}$ and $SOVO_{2max}$ protocols as well, further supporting the point that the uphill component is connected with the higher values of VO_{2max} that were observed during testing.

The fact that the uphill protocol elicited higher maximal oxygen consumption values than the horizontal protocol for all athletes tested is likely attributable to a multitude of factors. One main difference is that the uphill test likely required a larger amount of muscle mass recruitment than running at an equal intensity on a flat surface (Pokan, Schwaberger, Hofmann, Eber, Toplak, Gasser, Fruhwald, Pessenhofer, and

Klein, 1995; Sloninger, Cureton, Prior, and Evans, 1997). Although previous research discovered that uphill protocols typically elicit higher maximal oxygen consumption values than horizontal protocols, the subject pools that have been previously examined were not consistent between studies and did not include athletes of a high level. The current study examined elite athletes who were very specifically trained, yet the uphill protocols still elicited higher maximal oxygen consumption values in this new population.

The data gathered for lactate in this study, although as an exploratory variable, supports the idea of increased muscle mass activation during the GOVO as opposed to SOVO protocol. Lactate values collected after completion of the SOVO protocol were significantly lower than values collected after completing the GOVO protocol, at a difference of nearly 2 mmol/L. This difference supports the idea that there was an increased amount of muscle activation in the GOVO protocol when compared with the SOVO protocol. An increase in muscle activation during maximal exercise would entail a greater recruitment of Type-IIa and Type-IIb fibers which are known to produce higher amounts of lactate when used during exercise. In hindsight, it would have been ideal to collect lactate data after completing the familiarization trial of the Bruce protocol as well, which would have provided an additional comparison to elucidate the connection between running uphill and increased lactate production. However, this consideration was not made in advance and could be an area of future research as a result.

Another reason that the SOVO protocol elicited lower VO_{2max} readings than the GOVO protocol may be connected to the speeds experienced during the flat, SOVO protocol. Numerous subjects commented on the fact that they felt in control of their breathing at the upper stages of the SOVO protocol, yet felt as if their legs could not keep up with the pace being demanded by the treadmill. This indicates the possible presence of neuromuscular limitations within the subject population that may have inhibited their ability to reach a true maximal effort in terms of VO_2 even though they had reached a maximal running speed. Further examination of the experimental methodology supports this idea, as the testing period for the experiment took place mostly during the summer and fall when high levels of speed training do not typically occur in standard American training practices. As a result, it is possible that the true speed-training adaptations needed to perform better on a flat protocol such as the $SOVO_{2max}$ were not in place and thus limited the effectiveness of the study for those subjects who considered themselves flat runners. This type of study should be conducted during the period of time when an athlete is in peak shape, as this is likely to be the point at which they are the most specifically trained to meet the demands of their event. Further experimentation should attempt to examine this issue during the peak competitive season for an athlete, although this could be difficult. Both athletes and coaches can be hesitant to perform maximal exercise testing during this period of time due to the possibility of interfering with standard training practices during a crucial point in the competitive year. Overall, it is concluded that the results do not support the idea of treadmill protocol selection in terms of training specificity for high-level distance runners.

% VO_2 at Ventilatory Threshold

When compared between the $SOVO_{2max}$ and $GOVO_{2max}$ protocols, the percentage of VO_{2max} at which the ventilatory threshold occurred (%VO_2 @VT) was not significantly different. The two protocols produced values that were separated by a mere 0.3%, showing similar ability between these two tests to produce consistent values for ventilatory threshold. When compared to the Bruce protocol, the $\%VO_2$ @VT for both the $SOVO_{2max}$ and $GOVO_{2max}$ protocols was not significantly different. These results are not surprising when framed in terms of the physiological response to progressive exercise. Although maximal oxygen consumption values were different among the $SOVO_{2max}$ and $GOVO_{2max}$ protocols, it is not surprising that the percentage of maximal oxygen consumption where the anaerobic threshold (as estimated by ventilatory threshold) is crossed was not different between tests. Up until the point of crossing the anaerobic threshold, muscle recruitment should be very consistent among subjects completing different protocols. Prior to crossing the AT, the recruitment of Type-I fibers predominates muscle activity. Once this point is crossed, the recruitment of Type-IIa and Type-IIb fibers increases greatly to support the increased energy cost of running through anaerobic metabolic input. From the results, it appears that the $GOVO_{2max}$ protocol became increasingly more taxing on the subjects after this point in time, likely due to the fact that the grade increased to such extremes that a very large amount of muscle mass was activated to meet the energy demands, supporting this same scenario that was discussed earlier.

If athletes and coaches are interested in determining the $\%VO_2$ @ VT in order to dictate training intensities, these results indicate that the selection of test protocol is not of great importance. As a result, these individuals should choose a protocol that the athlete is most comfortable with as no statistical differences will be seen in the values produced for $\%VO_2$ @ VT.

In summary, it is concluded that both the SOVO and GOVO protocols can be utilized to measure the percentage of maximal oxygen consumption at which the ventilatory threshold occurs in high-level distance runners, as validated by the Bruce protocol. This similarity was not observed when comparing the absolute value of VO_{2max} at the ventilatory threshold point when measured with the GOVO and SOVO protocols.

Absolute VO_2 at the Ventilatory Threshold

Although this variable falls outside the range of the hypotheses tested in the study, exploratory analysis was conducted on the absolute value of oxygen consumption at the ventilatory threshold between the $SOVO_{2max}$ and $GOVO_{2max}$ protocols. Absolute VO_2 at the ventilatory threshold point was found to be significantly higher during the $GOVO_{2max}$ protocol when compared to the $SOVO_{2max}$, by an average of 4 ml/kg/min. This is a surprising result due to the fact that the %VO_2 @ VT was similar between the $SOVO_{2max}$ and $GOVO_{2max}$ while absolute values of oxygen consumption were not. Further evaluation of the results makes this scenario even more interesting, as it becomes clear that the VO_{2max} differences between $SOVO_{2max}$ and $GOVO_{2max}$ are similar to the absolute VO_2 @ VT differences between the protocols, keeping the ratio the same between where the VT occurs in reference to VO_{2max}. To explain this phenomenon, RER data was examined in an exploratory nature at the point of VT across all three protocols. RER values were consistently similar at VT no matter which protocol was being used, despite the fact that VO_2 values were not similar at this point in time as confirmed by statistical analysis. Although the treadmill protocols were matched for metabolic energy cost at each stage, it is likely that the $GOVO_{2max}$ protocol was more difficult at the point of VT in comparison to the $SOVO_{2max}$, causing VO_2 to be slightly elevated through increased muscle mass and an increased neural drive on ventilation. It is likely that the speed of the $SOVO_{2max}$ protocol was not fast enough at the point in time where the VT was reached to elicit a high level of oxygen consumption, considering most subjects seemed very controlled on the test until the final two or three stages beyond 11 miles per hour. Subjects typically showed signs of distress in the earlier stages during the $GOVO_{2max}$ protocol, likely due to the strenuous nature of moving that same load uphill. As the maximal values for all physiological data suggest that the $GOVO_{2max}$ was a more physically taxing protocol overall, it is likely that this trend would be exhibited in submaximal stages as well during the test. Nevertheless, a small difference in absolute VO_2 at the ventilatory threshold in high-level athletes is likely of minimal clinical or athletic significance.

When compared independently to the Bruce protocol, the $SOVO_{2max}$ protocol was not significantly different in absolute VO_2 @ VT. The $GOVO_{2max}$ protocol was also not significantly different when compared to the Bruce protocol for this same variable, although the results were approaching significance with a ~2.5 ml/kg/min increase seen in the $GOVO_{2max}$ ($p = 0.061$). It is likely that this can be linked to the combined speed and grade of the $GOVO_{2max}$ protocol being more strenuous than the Bruce at the point of VT also. It should also be considered that the length of stages for the Bruce protocol is 3 minutes while the $GOVO_{2max}$ is only 1 minute per stage. It is possible that the subject reached a comfortable steady state during the longer stages of the Bruce, allowing a lower, stable VO_2 to be maintained at the VT point due to a higher level of relative comfort during the test. During the $GOVO_{2max}$, subjects were constantly increasing the intensity of exercise every minute, making it likely that VO_2 was elevated and not stable at this point as a true steady state was never reached.

Other Considerations

From examining all of the physiological data collected during the study, it appears that the $GOVO_{2max}$ protocol was more metabolically taxing than the $SOVO_{2max}$ protocol, despite efforts to design protocols that were consistent in terms of energy cost per stage. Based on the commonly used criteria for the determination of VO_{2max} in this study, the results do not support the notion that these tests are equal in terms of difficulty. At the maximal stages of these tests, average data collected for RER, ventilation, VO_2, and lactate were all significantly higher in the uphill protocol, indicating that the GOVO protocol was more strenuous in nature when compared with the $SOVO_{2max}$. The fact that all subjects were determined to have met a maximal effort during both the $GOVO_{2max}$ and $SOVO_{2max}$ based on the criteria set for the study, even though the VO_{2max} results were significantly different between the protocols, indicates a potential flaw in the previously accepted maximal exercise criteria in this subject population. As a result, it may be necessary to re-examine the criteria used for the determination of a maximal effort in elite-level distance runners.

In talking with the subjects extensively after testing, many complained that they felt like they could not force the expired air out of the mask fast enough during the $SOVO_{2max}$ protocol. As a result, the subjects felt as if they could not breathe appropriately which could have produced a negative effect on the measurement of VO_2 during the $SOVO_{2max}$ protocol. They also mentioned that they felt like their legs gave out in terms of power output before their cardiovascular systems were truly maxed out. This shows that the $SOVO_{2max}$ protocol may not be practical if it is used for runners who are not in peak physical shape at the time of testing. A subject may need to be extremely well trained at the point in time at which they are tested on the $SOVO_{2max}$ protocol, in order to handle the very high speeds achieved during the test, for the results to reflect a true maximal effort.

In comparing the $GOVO_{2max}$ with the Bruce protocol, the two treadmill tests produced physiological data that was extremely comparable. There were no significant differences noticed in any of the variables examined in this study, indicating a high level of similarity between the two tests. Many subjects also commented that the running speed of the $GOVO_{2max}$ protocol was much more comfortable in comparison to the Bruce, and favored completing the $GOVO_{2max}$ protocol instead. As a result, it is concluded that the $GOVO_{2max}$ protocol is a valid test to determine maximal oxygen consumption in long distance runners.

In terms of protocol preference, every subject commented after the study that they preferred completing the $GOVO_{2max}$ protocol instead of the $SOVO_{2max}$ or Bruce protocols. Subjects mentioned that the $SOVO_{2max}$ seemed more difficult to complete, which likely reflects on the fact that the testing was conducted outside of their peak competitive period so the speeds were difficult to maintain. Although the maximal speed of the test (4:18/mile) was slower than the subjects' personal record pace for a 1 mile race, the duration at which they had to hold a high fraction of this speed seemed to be too great to overcome. As a result, it is imperative that the $SOVO_{2max}$ protocol be re-evaluated and adjusted for future research.

Future Recommendations for Research

From the findings of this study, research on this topic could span out in many different directions. Although the results do not indicate that training specificity has any effect on performance on varying treadmill protocols, it is likely that future studies could produce different results if adjustments are made to the experimental methodology. It is recommended that a similar study be performed while athletes are in the peak competitive part of their season to get a more accurate representation of specific fitness in terms of an athlete's event.

Although efforts were made to recruit subjects of both genders, only male long distance runners volunteered for the study. As a result, future research could reproduce this study using female subjects so that results may be generalizable to a larger group of individuals of both genders.

Also, as the $SOVO_{2max}$ protocol seemed to be flawed in terms of design, it is recommended that a similar study be conducted comparing a previously validated horizontal protocol with the $GOVO_{2max}$ to determine the effects of event specificity on treadmill test performance.

Finally, as the ventilatory threshold did not occur at the same absolute VO_2 between the $GOVO_{2max}$ and $SOVO_{2max}$ protocols, it would be interesting to confirm this result by examining the lactate threshold invasively while performing progressive, non-continuous treadmill tests that vary in speed and grade in this subject population. If absolute VO_2 was the same between an uphill and horiztonal test at the lactate threshold point, this may confirm that the use of ventilatory threshold to prescribe training intensities in highly-trained distance runners is not effective.

Overall, it is recommended to use the $GOVO_{2max}$ protocol when testing long-distance runners for VO_{2max} data to use in the design and implementation of exercise training programs. The results also indicate that both the $SOVO_{2max}$ and $GOVO_{2max}$ protocols can be used to determine the % VO_{2max} @ VT in highly-trained distance runners, so it is recommended to choose the protocol that is most preferred by the subject. It is also recommended to use the same protocol for testing both before and after a training intervention to provide an accurate look at the efficacy of the training program on inducing positive changes in fitness and exercise performance.

Appendix I

Par-Q

Please read the questions carefully and answer each one honestly: check YES or NO.

	YES	**NO**
1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?		
2. Do you feel pain in your chest when you do physical activity?		
3. In the past month, have you had chest pain when you were not doing physical activity?		
4. Do you lose your balance because of dizziness or do you ever lose consciousness?		
5. Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?		
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?		
7. Do you know of any other reason why you should not do physical activity?		

"I have read, understood, and completed this questionnaire. Any questions I had were answered to my full satisfaction."

Name: ____________________________ Signature: _________________________

Date: _____________________________

Appendix II

BASELINE MEASUREMENTS QUESTIONNAIRE

Subject ID: ______________________________

DEMOGRAPHICS & ANTHROPOMETRICS

Gender: M / F   Age: ____________years

Height: ______________ cm   Body Mass: ____________ kg

ANSWER THE FOLLOWING: (please circle)

1) Which type of running do you prefer? TRACK or CROSS-COUNTRY/ROAD

2) Do you consider yourself a good uphill runner? YES or NO

EATING & SLEEPING PATTERNS

Normal Bed Time: _______AM / PM

Normal # Hours of Sleep: ___________

Normal # Meals per Day: ________________

Appendix III

THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

Claudio Battaglini, Ph.D.

Ryan Vanhoy, B.S.

Department of Exercise and Sport Science

125 Fetzer Hall, CB # 8700

(919) 843-6045 / Claudio@email.unc.edu, rvanhoy@email.unc.edu

PRE-TEST GUIDELINES

1. No eating 4 hours prior to testing.
2. Void completely before testing.
3. Maintain proper hydration prior to testing.
4. Please wear appropriate clothing/shoes for testing (running shorts/shirt/shoes)
5. No exercise 12 hours prior to testing.
6. No alcohol consumption 48 hours prior to testing.
7. No diuretic medications 7 days prior to testing.
8. Sleep at least 6 hours the night prior to testing.

Source: Advanced Fitness Assessment and Exercise Prescription – Third Edition – Vivian H. Heyward

Appendix IV

PRE-TRIAL TESTING QUESTIONNAIRE

TRIAL 1

SUBECT ID : ___________________

Date: __________________ Time: ____________ AM / PM

Protocol: SOVO / GOVO

EATING & SLEEPING PATTERNS

Bedtime: __________ AM / PM # Hours of Sleep: _______________

Time of Last Meal: __________AM / PM # Meals Today: _______________

PHYSICAL ACTIVITY PREPAREDNESS

Perceived Fatigue: (none) 0 1 2 3 4 5 (want to go to sleep)

Muscle Soreness: (none) 0 1 2 3 4 5 (unbearable)

SPECIFIC GRAVITY EVALUATION RESULT:

____

Appendix V

PRE-TRIAL TESTING QUESTIONNAIRE

TRIAL 2

SUBECT ID : ___________________

Date: __________________ Time: _____________ AM / PM

Protocol: SOVO / GOVO

EATING & SLEEPING PATTERNS

Bedtime: ___________ AM / PM # Hours of Sleep: ________________

Time of Last Meal: ___________AM / PM # Meals Today: ________________

PHYSICAL ACTIVITY PREPAREDNESS

Perceived Fatigue: (none) 0 1 2 3 4 5 (want to go to sleep)

Muscle Soreness: (none) 0 1 2 3 4 5 (unbearable)

SPECIFIC GRAVITY EVALUATION RESULT:

____

WHICH TEST PROTOCOL DID YOU PREFER? (please circle)

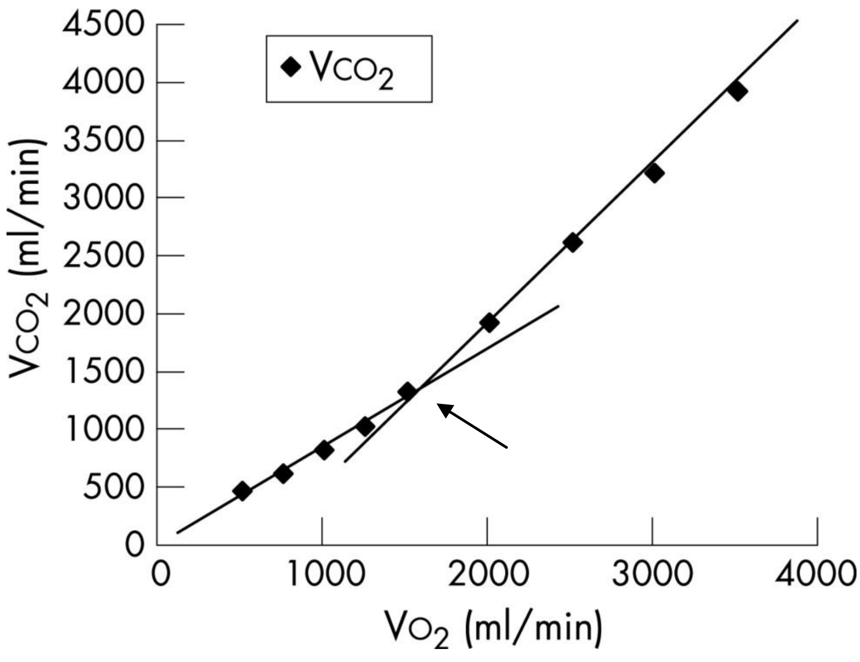
$SOVO_{2max}$ or $GOVO_{2max}$

Appendix VI

Modified V-Slope Method for Determining Ventilatory Threshold

- To determine ventilatory threshold in this experiment, the modified V-slope method will be employed as follows:

    1. Carbon Dioxide output (VCO_2) is plotted against oxygen consumption (VO_2) as measured per minute during exercise.
    2. A line with a slope of 1 is drawn through the points on the graph during the early phase of exercise.
    3. The point on the line where VCO_2 departs drastically from VO_2 (break-away point) will be marked as the ventilatory threshold. The VO_2 value at this point will be recorded and reported as a percentage of VO_{2max}.



Khaled, A., Egred, M., Alahmar, A., Wright, D.J. (2007). Cardiopulmonary exercise testing and its application.

Postgrad Med J. 83:675-682

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