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EFFECTS OF AEROBIC AND ANAEROBIC TRAINING PROTOCOLS ON 4000M TRACK CYCLING TIME TRIAL

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Kinesiology

by

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B.S., Louisiana State University, 1999
December 2004

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Abstract

The aim of this study was to determine whether performance in a 4000m individual pursuit could be significantly influenced by training protocols that are solely based in either aerobic/distance training, or anaerobic/sprint training. Faina et al., (1989) and Neuman et al. (1992) have found, using professional track cyclist that there appears to be a split in energy pathways used to perform the event. Their results indicate that 20% of the workload is achieved via anaerobic metabolism and the remaining 80% are achieved through aerobic metabolism.

Group #1, followed a training protocol modeled after repeated, short duration, (<1:30.00s/1000m), high intensity sprinting. This particular training protocol may serve to utilize a greater proportion of its allotted time by generating beneficial metabolic adaptations that may possibly improve the subjects performance in the 4000m individual pursuit.

Group #2, trained primarily through aerobic means, followed the "more traditional" training method for such an event. This protocol consisted of cycling intervals of distances proportionally longer (>4000m) than that of the actual performance measure. A reasonable assumption could be made, that more could be achieved by improving that area which has an 80% influence over an individual's performance in a single event than that which only accounts for 20%.

Through metabolic and performance testing, the effectiveness of the 4-week training protocols were evaluated via specific values of interest (4000m performance, oxygen consumption, anaerobic threshold, power output and oxygen deficit). Results indicated improved 4000m performance for both groups, though no statistically significant difference between them.

Each training protocol attained their results through adaptations in various metabolic pathways. Though statistically the findings were unable to determine a more successful program, Group #1 yielded a 1.75% advantage over Group #2 in 4000m performance, post training.

Chapter 1. Introduction

1.1 Background

In order for exercise physiologists to construct and implement specific training programs, they must have access to the fundamental information concerning the qualities that contribute to successful athletic performance. This may include the development of a functional training model to determine the relative contributions and kinetics of metabolism and other physiological factors that contribute to performance. Knowledge of the kinetics of metabolism and complete understanding of the physiologic components that influence performance will enable exercise physiologists and trainers to effectively prescribe specific training programs, develop adequate assessment protocols and maximize training and competitive performance.

Though the practice of creating goal specific training protocols is not a recent phenomenon, within cycling, this formula has most often been utilized to develop training protocols specific to road racing and time trials for elite and professional athletes (Coyle et al., 1988; Krebs et al., 1986; Mella & Manfredi, 1987). To date, there has been a lack of research conducted to identify the physiological variables that contribute to successful training protocols for amateur cyclists competing in track cycling events.

Track cycling events range from 200m flying sprints, which last approximately 10-11 seconds for world class athletes to a 50 km points race, which can last up to one hour. Unlike road cycling and longer endurance track events, which rely on sub maximal aerobic pathways, athletes participating in short track events must rely on a combination of aerobic and anaerobic pathways (Neumann et al., 1992).

While research has been conducted to identify the various components of the energy systems and the physical characteristics that contribute to road cycling performance (Burke, 1986; Neuman et al, 1992; McLean and Parker, 1989; Pyke et al., 1989), few researchers have focused on the key physiological parameters associated with successful track cycling performance, specifically in the 4000m individual pursuit.

The 4000m individual pursuit requires that the athlete start from a stationary position and propel themselves forward on a fixed gear bicycle in an effort to complete the distance

as quickly as possible. This particular track cycling event lasts approximately 4:30.00 at the international level and generates a high demand for both aerobic and anaerobic metabolic pathways (Burke et al., 1981; Keen et al., 1985; Neuman et al., 1992). Various studies have suggested the relative contributions of aerobic and anaerobic pathways in this event are approximately 80% and 20%, respectively (Neuman et al., 1992). Therefore, in order for exercise physiologists and trainers to create successful training protocols specific to the 4000m individual pursuit, a more complete understanding of physiological parameters related to track performance is essential.

The aim of this study was to determine whether performance in a 4000m individual pursuit could be significantly influenced by training protocols that are solely based in either aerobic/distance training, or anaerobic/sprint training. Faina et al., (1989) and Neuman et al. (1992) have found, using professional track cyclist that there appears to be a split in energy pathways used to perform the event. Their results indicate that 20% of the workload is achieved via anaerobic metabolism and the remaining 80% are achieved through aerobic metabolism.

Chapter 2. Review of Literature

2.1 Physiological Aspects of Cycling

Cycling, like all modes of human locomotion, requires the conversion of metabolic energy into mechanical power. Mechanical power applied to the pedals of the bicycle is transferred through the bicycle drive train to overcome the physical forces that resist bicycle motion (Ryschon, T., 1994) The athlete and the exercise physiologist share a common interest in the processes involved in the storage, liberation and utilization of metabolic energy, because each process can have a substantial influence on cycling performance. A complete understanding of the metabolic demands of cycling cannot exist without an appreciation of the physical forces that resist bicycle motion. Body size, state of conditioning and health, biomechanical factors and technologic innovations in bicycle design can each have dramatic effects on energy expenditure (Ryschon, T, 1994).

The bulk of energy expenditure cost during cycling occurs within in the contracting skeletal muscles (Ryschon, T., 1994). Other systems that support the metabolism of skeletal muscle also consume energy and if active at high levels can potentially divert fuel from the working muscle resulting in lower cycling speeds for a given environment. The working mass of skeletal muscle is at the center of this complex physiologic response. Cyclists have control of several factors that can affect the energy cost of cycling through their effects on muscle energetics. These factors include bicycle geometry (seat height, crank arm length), pedal cadence, pedal-shoe linkage, body posture and riding technique.

Studies have demonstrated the significant influence of seat height on joint range of motion during cycling (Nordeen & Cavanagh, 1975). Energy economy has been found to be optimal when the seat height measures 105% to 108% of the distance between the symphysis pubis and the floor (Nordeen-Snyder, 1977; Schennum, 1976). Using a saddle height 109% of symphysis pubis-floor distance has been associated with increased power output during indoor cycle ergometry (Hamley & Thomas, 1967). The observation that electromyography (EMG) of quadriceps muscle increases as seat height is decreased lead researchers to suggest that optimal saddle height ranges can be partly explained by muscle recruitment patterns (Jorge & Hull, 1986).

Competitive cyclists typically prefer cadences between 80 & 110 rpm during competition (Haberg et al., 1979; Marion & Leger, 1988; Patterson & Moreno, 1990). Based on studies using competitive cyclists riding at 80% to 85% of $VO_{2\ max}$ in which VO_2 was used as a measure of energy expenditure, optimal cadence (the pedal speed associated with the lowest VO_2) ranged from 60 to 91 rpm (Coast et al., 1986; Hagberg et al., 1981; Ryschon & Stray-Gunderson, 1991). Biomechanical studies have shown that both muscle stress and force at the pedal are minimized between 90 and 100 rpm (Hull et. al., 1988; Patterson & Moreno, 1990; Redfield & Hull, 1986) suggesting competitive cyclists use cadence more for its ability to minimize necessary leg force (and fatigue sensation) than for its energy conservation potential. A study using untrained cyclists, however, suggests that biomechanically and metabolically optimal pedal rates do in fact coincide when the criteria for the latter considers both internal and external work being performed (Widrick et al., 1992).

Direct measurement of forces exerted to the pedal have emphasized the importance of shoe-pedal linkage. Traditional pedal retention systems used by racing cyclists significantly improve mechanical efficiency compared with platform pedals that use no shoe retention device (Davis & Hull, 1981). Researchers can partly explain this phenomenon by a decrease in quadriceps activity and muscle force during the down stroke of the pedal cycle that can be attributed to the active lifting of the opposite leg that is facilitated by pedal retention systems (Jorge & Hull, 1986; Ryschon, T., 1994). As a result of these findings, pedal retention use by trained cyclists would be expected to lower perceived exertion, improve economy, reduce ventilation and lower heart rate at a given submaximal work rate. Studies using trained cyclists have not detected any difference in perceived exertion (Brodowicz et al., 1991; Coyle et al., 1988) or cardiorespiratory parameters (Coyle et al., 1988) between pedal retention and platform pedal use, which suggests physiologic measures are insensitive to this particular mechanical effect.

Studies that have used VO_2 as a measure of energy expenditure report considerable variation (20% of mean) in optimal cadence within groups of trained cyclists. This variation appears to be related to muscle fiber type because cyclists with higher percentages of ST fibers in their vastus lateralis muscles demonstrate increased economy when using relatively low pedal cadences (60 vs 100 rpm) at a giver percentage of $VO_{2\ max}$ (Suzuki, Y. 1979; Ryschon, T., 1994).

The leg muscles of the cyclist are not the only active energy consumers during cycling. Less obvious but equally important activity is occurring in the muscles of the neck and back for postural support as well as the arms that aid in force application and partial upper body support. The activity of "postural" muscles and their contribution to total energy requirements of cycling activity has not been determined (Ryschon, T, 1994).

Handlebars allow several options for trunk orientation, from upright riding with hands on the brake hoods to a more horizontal trunk orientation achieved by using aerobars. These positions have definite implications on air resistance; however, their primary effect on energy cost in the absence of moving air have been investigated as well. VO_2 measurements during submaximal steady state cycling have not indicated any differences in economy between riding in the lower portion of standard road handlebars and upright body position (Ryschon & Stray-Gundersen, 1991) nor between aerobar use and upright positioning (Johnson & Schultz, 1990). Measurements of $VO_{2\ max}$ using standard drop positioning were slightly higher (Faria et. al. 1978) or not different from (Welbergen, 1990) measurements in the upright position. Maximal mechanical power output, is higher for upright cycling, relative to the dropped position, (Welbergen, 1990) suggesting that biomechanics are more optimal in this position allowing greater participation of upper body musculature.

Muscles of the arms are particularly active during high intensity cycling. Arm muscles assist in optimal power application to the pedals and control motions of the cyclist's center of gravity. The activity of arm musculature is evident during sprinting and standing cycling. Increased activity of postural muscle groups (arms, neck and back) during standing as compared with seated cycling has been suggested to explain portions of the 12% increase energy cost of standing cycling performed on an inclined indoor treadmill (isolated from the effect of air resistance) (Ryschon & Stray-Gundersen, 1991). Quantifying the specific contribution of postural muscles to total cycling energy expenditure is difficult, due in part to the involvement of several different muscle groups, as well as complex blood flow and neural activation patterns.

Throughout incremental, upright cycle ergometry, the following cardiovascular adjustments occur: (1) right atrial pressure is increased, initially by a large amount (related to the increase in central blood volume) followed by an unexplained but lesser increase at high heart rates and work rates; (2) left and right ventricular filling pressures and stroke volumes increase until a plateau is reached at high work rates; (3) heart rate increases to

produce further increments in cardiac output above the plateau in stroke volume; and (4) right atrial and pulmonary wedge pressures increase in parallel (Reeves, et al, 1990). Beyond supporting muscle blood flow, these alterations in central hemodynamics can explain the increases in pulmonary artery pressure, right ventricular work, and lung fluid filtration that occur with cycling exercise (Reeves et al., 1990). The increase in cardiac output that occurs requires a higher rate of energy production that is met by an increase in coronary flow and greater oxygen extraction (Rowell, 1986).

The ability to increase cardiac output by augmenting stroke volume early in exercise may be training-specific because researchers have not been able to observe this phenomenon in untrained subjects (Schairer et al., 1991). Research indicates that both left ventricular end-diastolic volume and left ventricular mass are increased in trained male and female cyclists, (Milliken et al., 1988; Riley-Hagan et al., 1992) which are adaptations that support large stroke volumes while maintaining normal levels of wall stress. Still, endurance cyclists are unable to maintain augmented stroke volumes at constant levels during prolonged cycling at 70% to 80% of $VO_{2\,max}$ and cardiac output falls despite further increases in heart rate; a phenomenon known as "cardiovascular drift" (Rowell, 1974). Although "cardiac fatigue " (Tibbits, 1985) with impaired systolic shortening and abnormal patterns of diastolic filling may explain a portion of this phenomenon, (Douglas et. al., 1987) all of its elements, including a gradual increase in VO_2, are avoidable by fluid replacement and glucose ingestion during prolonged cycling (Hamilton, 1991).

During cycling, muscle fibers convert 25% to 30% of metabolic energy into useful tension, with the remainder resulting in heat energy. Limitation in exercise capacity due to elevated body temperature (Mac Dougall, 1974) is averted during sustained exercise by transporting this heat energy to the skin surface where it can be dissipated by convection, radiation and evaporation depending upon environmental factors (ambient temperature, relative humidity, radiant heat and airflow) that generate climatic heat stress. Of these factors, airflow is typically of greatest importance to temperature dissipation in cyclists. During outdoor road cycling, airflow over skin surfaces increases heat loss by improved evaporation and convective transfer. This is clearly demonstrated in comparisons of endurance capacity between indoor ergometry and outdoor cycling. Above a power output of 150 watts (W) the limited airflow available during indoor cycle ergometry results in net heat accumulation, temperature elevation and volitional fatigue after several minutes,

whereas the same cyclist can effectively dissipate the heat generated during a 1 hour, outdoor time trial at a power output of 224W (Whitt & Wilson, 1985).

Because heat dissipation is a function of available surface area for heat exchange, the relatively large surface area to body weight ratio of smaller cyclists should allow these cyclists to dissipate heat more effectively than larger cyclists (Swain et al., 1987). Cycling apparel, including helmets, although traditionally disdained among cyclist for being too warm, have no discernible adverse influence on heat dissipation, body temperature or cardiovascular function during prolonged outdoor cycling (Gisolfi, 1988).

The cardiovascular system must transfer heat energy to the surface of the body while supplying blood flow to working muscle. This distribution of blood flow is altered in hotter, more humid environments resulting in diversion of more flow to the skin and potentially causing a reduction in maximal work capacity (Wyndham, 1973). Cycling in extremely hot and humid conditions that limit heat dissipation can place potentially dangerous demands on the cyclist's cardiovascular system.

As respiratory rate accelerates to meet the increased demand for gas exchange during exercise, the respiratory muscles must increase their power output through increased ATP synthesis or glycolysis. The contribution of these muscles to total body VO_2 has not yet been directly determined because of the involvement of multiple, anatomically distant groups and their diverse blood supply network. Indirect determination suggests that respiratory muscles contribute approximately 5% of the total VO_2 during cycling and that this percentage is constant across intensities implying that work performed by the diaphragm at high total body work rates is supported by glycolytic metabolism (Coast et al., 1993; Astrand et al., 1986).

2.2 Physiological Determinants of Successful Track Cycling

Competitive cycling is a physiologically demanding sport. Typically, races range from short sprints lasting 10-11 seconds to stage races such as the Tour de France and Giro d' Italia, which take place over a two-week period and traverse approximately 5000 kilometers. This wide range of race distances within competitive cycling has resulted in cyclists specializing in events, which place specific demands on particular metabolic energy producing pathways.

Unlike road cycling where most racing is performed at a sub maximal power output, many track events require the cyclist to exhaust both the aerobic and anaerobic metabolic pathways (Faria, I., 1984; Craig, N. & Norton, K., 2001). An elite track cyclist possesses several key physiological attributes that are matched with their specific event. These cyclists, with the appropriate genetic predisposition, can maximize those traits through effective training interventions. Typically, competitive male cyclists demonstrate a wide range of values for their physical characteristics.

The average age of a typical professional cycling team is approximately 26 years of age, with ages ranging between 20 to 33 years old (Craig, N. & Norton, K, 2001). Besides age, anthropometric measures play a large role in competitive cycling. Generally, a successful competitive cyclist possesses a relatively low body fat percentage. A higher mesomorphology is common in shorter track events and progressively decreases as the distance of the events increase. For example, track sprint specialists are generally shorter in stature when compared to endurance track riders (McLean, B, & Parker, A, 1989). In addition, sprinters are most often significantly heavier and stronger than those specializing in endurance events. Conversely, track cyclists participating in longer endurance related events possess a taller stature with a longer leg-to-height ratio compared to other cyclists. Individual track time trial specialists and pursuiters are generally the tallest among track cyclists and possess the most ectomorphic body shape. This reduces the amount of aerodynamic drag of the upper body and allows them to use a much higher gear ratio as compared to smaller competitors.

It is generally accepted that a low relative body fat percentage is most desirable for performance in any sport, as additional body fat adds to the mass of the body without contributing to its force or energy contributing capabilities. With respect to track cycling, increased nonfunctional mass has the triple effect of decreasing performance since it increases the energy cost of acceleration, rolling resistance and the projected frontal area of the cyclist (Craig et al., 2001). Therefore, it is not suprising that highly competitive track cyclists average among the lowest levels of body fat of any sport (Craig et al., 2001). Old et al. (1993) estimated that an increased body fat mass of 2 kg increased a 4000m individual pursuit cycling performance by about 1.5 seconds, which equates to a distance of approximately 20m. Research conducted by Kyle et al. (1988) produced similar findings,

revealing that a 3.5% increase in nonfunctional mass increased a track cyclist's time over 1000m by 0.15 seconds.

A competitive track cyclist also exhibits a significantly high oxygen uptake value, ventilatory threshold value, maximal accumulated oxygen deficit, maximal power and strong quadriceps. Successful track riders possess a high oxygen uptake value and the ability to rapidly reach and sustain a high maximal oxygen uptake. One of the most important traits among cyclists is their high aerobic capacity as demonstrated by maximal power output and maximal oxygen consumption. High aerobic power has been found to be closely associated with track cycling success (Craig & Norton, 2001).

In addition to maximal physiological characteristics, sub maximal characteristics play a significant role in the success of a track cyclist. Typical physiological characteristics of competitive track cyclists at individual lactate threshold (LT) include power output of 334W (76% Wmax), oxygen uptake of 4.0 L/min (77% of $VO_{2\ max}$) and a heart rate (HR) of 163 beats/minute (84% HRmax). Typical values correlating with the onset of blood lactate accumulation are 386W (87%Wmax), 4.5 L/min (86% $VO_{2\ max}$) and 178 beats/minute (92% HRmax), respectively (Craig & Norton, 2001). Therefore, trainers and exercise scientists often develop training programs that require cyclists perform at a high aerobic capacity for a prolonged period of time, stressing the body's oxygen transport system maximally, and the majority of track cycling training focuses on improving the oxygen transport systems or maximal oxygen consumption ($VO_{2\ max}$) despite the fact that track cycling is highly specialized and consists of numerous events which vary greatly in length and composition.

Track events, such as match sprints, rely heavily on the ATP-CP energy system, while events such as the Kilo and 4000m individual pursuit rely on both the ATP-CP system and the glycolytic and lactic acid energy sources and longer, endurance based track events rely on the oxidative breakdown of carbohydrates and fats for energy. Because track cycling is a highly specialized form of cycling and consists of numerous events, it has been suggested that specific training protocols should be developed for each type of event. In addition, recent research has shown that it is important that the majority of competitive track cyclists should incorporate training programs that stress both the aerobic and anaerobic pathways.

2.3 Measurements of Cycling Performance

Regular training induces major physiological and biochemical adaptations in a variety of systems within the human body. It has been well established that skeletal muscles undergo increases in oxidative potential, which contributes to improvements in work capacity as a result of constant training. The most important adaptive response in terms of cycling is the augmentation of the cardiorespiratory capacity. Other adaptations in response to training include alterations in glycolytic capacity and ATPase activity.

Historically, researchers have typically measured successful cycling performance by testing an athlete's maximal oxygen uptake ($VO_{2\ max}$), power output, and blood lactate concentrations. However, many of the techniques used to measure these physiological parameters are very expensive, time-consuming, and invasive. Therefore, research has suggested using other physiologocal parameters, in addition to the gold standard methods, to determine succesful cycling performance. By including the measurement of cycling parameters such as maximal accumulated oxygen deficit and ventilatory threshold, in addition to maximal oxygen consumption, maximal power output, and blood lactate concentrations, it becomes possible for exercise physiologists to more adequately reveal all of the factors that contribute to the strengths and weaknesses of a cyclist's performance.

2.3.1 Maximal Oxygen Consumption ($VO_{2\ max}$)

Maximum oxygen consumption ($VO_{2\ max}$) is one of the main variables used in the field of exercise physiology and is frequently used to indicate the cardiorespiratory fitness of an individual. In scientific literature, an increase in $VO_{2\ max}$ is the most common method of demonstrating a considerable training effect.

$VO_{2\ max}$ is the product of maximum cardiac output and maximum arteriovenous oxygen difference.

$$V0_{2\ max} = (Q\ max)(a\text{-}vO_2)max \text{ (Hill et al., 1924)}$$

According to the first theory established by A.V. Hill in the early 1920's, $VO_{2\ max}$ is the point at which oxygen consumption fails to rise despite an increase in exercise intensity or power output. Simply stated, maximum oxygen consumption is defined as the highest rate at which oxygen can be taken up and utilized by the body during severe exercise. After

reaching $VO_{2\ max}$, an individual is able to exercise at a higher intensity by using non-oxidative metabolism. This theory suggests that as the heart reaches its maximum pumping capacity, the skeletal muscles must, therefore, rely on anaerobic metabolism to continue activity (Faria et al., 1984; Bassett & Hawley, 2000). Additionally, this theory also states that the oxygen transport capacity as measured by $VO_{2\ max}$ determines fitness in most types of exercise and is a strong predictor of performance in endurance sports. Thus, $VO_{2\ max}$ determination has been used in the past and is still used to evaluate an athlete's level of training, to compare athletic ability between individuals, and to monitor adaptations throughout training and competition.

$VO_{2\ max}$ is typically determined by exercising subjects on a bicycle ergometer or treadmill. During a graded exercise test for $VO_{2\ max}$, the workload is increased until the point at which the subject reaches exhaustion. The amount of oxygen (L/min) consumed at the point of exhaustion is the maximal oxygen uptake (Faria et al., 1984).

Research has shown that demonstrating a high aerobic capacity is important for success in track cycling events (Craig et al., 1993). The ability to rapidly reach and sustain high maximal oxygen uptake enables a large, rapid and sustained aerobic energy release that reduces the reliance upon a large proportion of the finite oxygen deficit. $VO_{2\ max}$ values above 90 ml/kg/min have been found to exist in many world class track cyclists. As high aerobic power is strongly associated with track cycling success, peak $VO_{2\ max}$ values in excess of 80 ml/kg/min for males and 70 ml/kg/min for females are considered prerequisites for successful world-class cyclists. Because $VO_{2\ max}$ and its response to training are under strong genetic control, it becomes obvious that a high aerobic power base is mandatory for successful track cycling performance (Craig et al., 1993; Craig et al., 1995). This became apparent in a study conducted by Jeupendrup et al.(2000), who reported, that during the off season, a male track cyclist recorded $VO_{2\ max}$ values of 74.3 ml/kg/min; however, in preparation for the National Championships less than a year later, the same cyclist's $VO_{2\ max}$ values increased to 84.8 ml/kg/min. Variations in $VO_{2\ max}$ values have been shown throughout a training season as a result of alterations in the amount of training volume and training intensity. Sjogaard et al. (1985) reported changes of up to 22% in the relative $VO_{2\ max}$ values of track cyclists over a 12 month training period. In addition, Jeukendrup et al. (2000) reported longitudinal changes in aerobic indices over a six year period for elite male 4000m pursuit track cyclists. In terms of performance, Olds et al. (1993) predicted that a

15% improvement in $VO_{2\,max}$ (5.24 to 5.91 l/min) would enable a track cyclist to compete in the 4000m pursuit 15.5 seconds faster. Further, it has been demonstrated that elite cyclists exhibited physiological adaptations such as the ability to perform near 90% of $VO_{2\,max}$ over long periods of time. Therefore, the kinetics of $VO_{2\,max}$ among track cyclists has become a topic for research with regards to training protocols.

The average values for $VO_{2\,max}$ for elite cyclists range from 69.1 mL/Kg/min to 74 mL/Kg/min. While these values are moderately high, this data suggests that moderately high oxygen uptake capacities are required for successful competition (Craig and Norton, 2000). Jeukendrup et al (2001) revealed that novice cyclist with a relatively short history of cycling training demonstrate an increased $VO_{2\,max}$ of 20-38% after a 9-12 week training program. The most pronounced increases were observed in older cyclists where as the younger cyclists demonstrated small improvements in $VO_{2\,max}$. In another study conducted by Norris & Peterson (1997), researchers discovered that six competitive cyclists following an eight-week training program (5x/wk, 40-55min), improved $VO_{2\,max}$ by 5% within four weeks of training.

According to Craig et al. (1993), $VO_{2\,max}$ was significantly correlated with individual 4000m performance. Individuals with higher $VO_{2\,max}$ values significantly decreased individual pursuit times when compared to those with lesser $VO_{2\,max}$ values.

2.3.2 Power Output

One of the most outstanding characteristics among cyclists is their ability to generate a high maximal power output (Wmax). Power, defined as the rate of work production, has recently been proposed as a significant predictor of athletic performance (Hawley & Williams, 1991; Noakes, 1988; Noakes et al.,1990; Scrimgeour et al., 1996).

Power demands in cycling include the sum of the power necessary to overcome air resistance and rolling resistance, the power required to change the kinetic energy of the system and the power required to ride up and down changes in grade (Olds, 2001). Testing cyclists on a mechanically braked ergometer, Wmax values ranging between 349 and 525W (5.7-6.8 W/kg) have been reported (Padilla et al., 1999; Padilla et al., 2000).

Power profiles for cyclists competing in 4000m individual pursuit time trials, have been recorded by multiple researchers. Power output profiles for an elite male cyclist competing in a 4000m individual pursuit and an elite female competing in a 3000m pursuit

recorded average maximal power output values of 495 and 381W, respectively (Craig & Norton, 2001). In addition, Hawley and Noakes (1992) revealed a highly significant relationship exists between maximal power output and 20 Km time trial performances. Researchers also observed a significant relationship between the maximal power output that cyclists attained during a laboratory test to exhaustion and a 20 Km time trial. Therefore, they concluded the maximal power output attained during an exhaustive test can be considered a valid prediction of cycling performance time. Maximal power outputs have also been correlated with lactate threshold levels during exhaustive cycling exercise (Bishop et al., 1998). Using a group of amateur, well-trained cyclists, Bishop et al. (1998) revealed that maximal power output was a useful tool in the predication of endurance cycling performance.

This finding was analogous to the results of other studies conducted on swimmers and runners (Morgan et al., 1989; Noaks et al., 1990; Scrimgeour et al., 1986; Hawley et al. 1992), which have shown that measurements of maximal power output are better predictors of athletic performance than more commonly measured physiological variables.

In a similar study conducted by Balmer et al. (2001), results showed that a strong relationship exists between maximal power output and 16.1 Km cycling time trial. Thus, reserachers concluded that a change in maximal power output has a direct effect on cycling performance. Research has also demonstrated that maximal power output is a strong predictor of cycling time trial performance across a wide range of cycling abilities (Balmer et al., 2001). However, differences in maximal power output have been noted when comparing professional and elite cyclists. Lucia et al. (1998) compared the various physiological parameters exhibited by professional and elite cyclists, and results revealed, that with the exception of maximal power output, no other significant differences existed between these two groups. In addition to higher maximal power output when compared to elite cyclists, professional cyclists recorded a significantly higher overall power output. Submaximally, professional cyclists displayed a better cycling economy at various submaximal levels of power output.

Noted in a training study conducted by Lindsay et al. (1996), maximal power output increased in highly trained cyclists who completed a 4-week, high intensity, interval training program. Therefore, it has been postulated that cycling performance is a combination of a cyclist's maximal power output and their ability to sustain a high percentage of that maximal

power output for prolonged periods of time. Further, Lindsay et al. (1986) determined that maximal power output could account for 70-90% of the variation in cycling performance. Similarly, data from a study by Balmer et al. (2000) suggests that maximal power output can account for up to 98% in the variation of cycling performance and 21% of the variation in time trial performance.

It should also be noted that testing protocol and test duration could significantly affect the measurement of power output. Research conducted by Withers et al. (1993) demonstrated power output during four different treatment protocols, which all varied in length. Maximal power output was reached during the 5th second of the test, but this level could not be sustained for a lengthy period of time. Intra-class correlations indicated a high reproducibility in measurements for maximal power output among the four treatment protocols. No differences were found to exist between treatments. Therefore, Wither et al. (1993) concluded that maximal power output was independent of test duration and protocol.

In a study conducted by Craig et al. (1995), mean power output was tested in four supramaximal test durations. Results indicated a significant difference between the mean power output of each test when comparing sprint and endurance trained track cyclists with untrained individuals. Results revealed that in comparison to endurance cyclists, sprint cyclists recorded a significantly greater mean power output in the 70 second test protocol and a significantly lower mean power output in the 115% $VO_{2\ max}$ test protocol.

While maximal power output has been highly related to cycling time trial performance in distances ranging from 16-40 km, most of the data recorded has been collected from professional and elite cyclists. Few studies have been conducted to determine the maximal power output values for amateur, trained cyclist (Balmer et al., 2000; Bentley et al., 1998; Hawley et al., 1992; Weston et al., 1997). In a study conducted by Bentley et al. (2001), researchers investigated the relationship between power output and time trial performance in amateur, trained cyclists in time trial performances lasting 20 minutes and 90 minutes in length. Results showed that average power output. measured in watts, in the 20 minute and 90 minutes time trials was 323.7 and 284.3, respectively. When compared to the 90 minutes time trial performance, maximal power output was significantly less than the maximal power output for the 20 minute time trial performance, and researchers concluded that the 90 minute time trial performance was highly related to maximal power output at lactate threshold. However, in contrast, 20 minute time trial performance was only

moderately correlated with maximal power output. Further, researchers indicated that 20 minute time trial performance was not related to 90 minute time trial performance, thereby further emphasizing the differences in power output and performance. Maximal power output was highly related to average power output in the 90 minute time trial performance; however, it was not related to the performance in the 20 minute time trial and approximately 83% of variance in the 90 minute time trial was explained by maximal power output. Conversely, for the 20 minute time trial performance, only 29% of the variance in performance was explainable by the recorded maximal power output.

2.3.3 Maximal Accumulated Oxygen Deficit (MAOD)

The maximum amount of ATP that can be supplied by the anaerobic energy system is termed anaerobic capacity. Historically, researchers have directly quantified anaerobic energy from muscle biopsy samples that provide insight into the determination of anaerobic capacity throughout ATP-CP breakdown and muscle lactate concentrations. However, this procedure is invasive and quite expensive. Therefore, the measure of maximally accumulated oxygen deficit (MAOD) has been proposed as a measure of anaerobic capacity during exhaustive exercise. As proposed by Medbo et. al. (1988), MAOD relies on an extrapolation procedure using linear workload oxygen uptake based on a sub maximal graded exercise test. From this data, a regression line is drawn so that energy expenditure can be predicted.

MAOD is defined as the difference between the predicted supra maximal oxygen uptake and the actual oxygen uptake during exercise to fatigue, and this method has recently been adapted for use during all-out exercise as an alternative procedure for the assessment of anaerobic capacity (Withers et al., 1991, Withers et al. 1993). In addition, MAOD has been established as a valid tool with which to indicate the anaerobic comparisons between athletes (Scott et al., 1991).

In a study conducted by Scott et al. (1991), MAOD was significantly higher among sprint and middle distance athletes when compared to endurance athletes, which suggests a greater anaerobic capacity among sprint and middle distance athletes. Researchers Gastin & Lawson (1994) revealed that sprint trained athletes and endurance athletes recorded MAOD values which were 26 and 37% higher, respectively, when compared to untrained athletes. However, when the MAOD values of the sprint and endurance athletes were compared,

MAOD was not statistically significant (Gastin et al., 1994). This finding was directly contradictory to previous studies conducted by Scott et al., (1993), which demonstrated that sprint trained athletes recorded higher MAOD values as compared to endurance trained athletes.

MAOD has also been used as a tool to assess overall performance in track cyclists. According to research conducted by Medbo and Burgers (1990), results demonstrated that MAOD appears to be sensitive to differences in training status. These researchers established that MAOD increased by approximately 10% after six weeks of anaerobic training. In a study conducted by Craig et al., (1993), results indicated that MAOD values for track cyclists were significantly correlated with performance in the 4000m individual pursuit. Craig et al. (1993) reported MAOD values as high as 88.2 mL/ Kg, while Saltin et al., (1990), suggested that a MAOD value of 100 mL/Kg is a likely estimate for a highly trained 4000m individual pursuit specialist. Further, Old et al.(1993) demonstrated the practical benefits of specific anaerobic capacity training by suggesting a 10% increase in MAOD will decrease an individual 4000m pursuit time by approximately 15 seconds, further demonstrating the importance of increased anaerobic capacity in track cycling. The untrained and endurance trained subjects recorded MAOD values of approximately 2.86 +/- 0.10mmol/kg during two and three minute exhaustive exercise cycling bouts, and no significant difference was found to exist between the two groups. However, the sprint trained athletes recorded MAOD values which were 30% higher when compared to the untrained and endurance trained cyclists. In addition, during a 30 second sprint exercise, MAOD values were again found to be 30% higher for the sprint trained cyclists when compared to the untrained and endurance trained athletes. Therefore, based on the results of this study, researchers concluded that regular endurance training does not appear to influence anaerobic capacity or MAOD. In addition, absolute MAOD values for sprint trained cyclists during all-out cycling bouts were significantly larger when compared to endurance trained and untrained cyclists. These findings further support similar findings during exhaustive, constant intensity treadmill exercise (Medbo & Burgers, 1990; Scott et al., 1991).

While MAOD is often taunted as a valuable measuring tool for anaerobic capacity and performance, it has also been suggested that MAOD is a useful tool for indicating anaerobic energy release (Medbo & Tabatta, 1989). Results of their study revealed that

MAOD increased linearly with the duration of work at the rate of 37.7 +/- 1.2 mmol/kg/s. MAOD also increased with the duration of exhaustive exercise from 30 seconds to one minute, and a further increased was revealed when the exhaustive exercise bout was extended beyond one minute. Further, for exhaustive sprint cycling exercise, Medbo & Tabatta (1993) revealed that the anaerobic processes contributed to approximately 60% of energy released. Therefore, they concluded that a high MAOD value could possibly contribute to increased anaerobic capacity and performance, which further validated earlier research that suggested MAOD as a useful measure of anaerobic capacity and performance in track cycling. Theoretical calculations by Medbo et al. (1988) favorably compared MAOD with estimates in previous literature of the anaerobic energy release during exhaustive exercise bouts have been supported in small muscle group and whole body exercise (Bangsbo et al., 1990; Wither et al., 1991). Medbo & Tabatta (1993) also revealed that MAOD was correlated with the rate of muscle anaerobic ATP production during maximal cycling exercise. However, in contrast to this study, Green at al., (1996) found that MAOD was not significantly correlated with muscle anaerobic ATP production and therefore concluded that MAOD is not significantly related to anaerobic capacity.

While MAOD has been proposed as a measure of anaerobic capacity, a standardized length and method of testing has not yet been established (Bangsbo et al, 1990; Medbo et al., 1988; Medbo et al., 1989; Saltin et al., 1990; Scott et al., 1991). The measurement of MAOD, as proposed by Medbo et al., (1988), is based on several physiologic assumptions. It is thought that at least two minutes of supramaximal constant load exercise is required to fully exhaust the anaerobic capacity. Therefore, in relation to the 1000m track events, which are completed in less than 70 seconds at the international level, cyclists may not be able to take full advantage of the energy derived from anaerobic sources (Craig et al., 1995). However, Withers et al., (1991) and Withers et al., (1993) recently demonstrated that 60 seconds of all out supramaximal exercise may provide a valid assessment of MAOD. Furthermore, Craig et al. (1993) and Craig et al. (1989) conducted research which lead them to suggest that the most appropriate exercise duration for assessing MAOD may be event specific.

Craig et al. (1995) assessed MAOD for sprint and endurance trained cyclists under four different exercise durations (70 seconds, 120 seconds, 115% of $VO_{2\ max}$, and 300 seconds). Results revealed sprint cyclists achieved a significantly greater MAOD values

when compared to endurance track cyclists when a 70 second testing protocol was used. Although endurance cyclists achieved their greatest MAOD values during a 300 second testing protocol, no significant difference was noted during the three other test durations. However, it is important to note that during the 70 second protocol, the track endurance cyclists only reached 92.7% of the peak MAOD achieved during the 300 second protocol. Sprint cyclists recorded their greatest MAOD values during the 70 second supramaximal testing session. Additionally, Craig et al. (1995) demonstrated that sprint cyclist achieved higher MAOD values in the 70 and 120 second testing protocols as compared to the 115% $VO_{2\ max}$ and 300s protocols. These findings question the validity of using universally accepted testing durations and also have important implications when requiring a valid measure of MAOD in the different track categories (Craig et al., 1995). These results also lend themselves to help clarify the results of Craig et al. (1989), an earlier study which underlined the importance of test duration when relating to track performance and anaerobic capacity.

It is a common experience from a number of different sports that a proper application of anaerobic training increases performance during exercise sessions of short duration, and after 8 weeks of training, the muscle can more efficiently handle increased lactate production during a 30 second sprint (Neville et al., 1989). Therefore, some researchers have suggested that anaerobic capacity is an easily trainable physiological parameter.

Results from a study conducted by Medbo and Burger (1990) demonstrated that sprint trained athletes had a 30% greater MAOD value, and the anaerobic capacity for the sprinters who had participated in regular anaerobic training was greater when compared to anaerobically untrained individuals. This study also examined the differences in training intensity on MAOD values. The participants were divided into two groups - Group A and Group B. Group A worked at an intensity of 116% of $VO_{2\ max}$ and group B worked at an intensity level of 165% of $VO_{2\ max}$. Following six weeks of anaerobic training, MAOD values increased by 10% for both groups. These results lead researchers to the conclusion that anaerobic capacity can be improved after only six weeks of training despite the intensity of the training protocol.

2.3.4 Ventilatory Threshold

The anaerobic threshold has been studied thoroughly during the past decades, and it has been described using a variety of definitions. Since the introduction of the term anaerobic threshold by Wasserman et al. (1964), AT has been associated with an increased blood lactate concentration, increased ventilation, increased CO_2 excretion and a decreased bicarbonate concentration. Researchers have suggested that these increases reflect a shift from aerobic to anaerobic metabolism (Wasserman et al., 1964).

Anaerobic threshold is commonly defined as the highest metabolic rate at which blood lactate concentration is maintained at a steady state during prolonged exercise. This definition developed by Wasserman et al. (1964) is based on the assumption that exercise above a specific work rate stimulates recruitment of anaerobic, lactic acid producing energy metabolism; therefore, AT has been accepted as a tool for predicting endurance performance and for the development of training strategies for athletes.

When an individual exercises with progressive intensity, that individual experiences marked increases in blood lactate concentration (Green et al., 1983; Stegman et al., 1980) and ventilatory measures (Caiozzo et al., 1982; Wasserman et al., 1967). Using blood lactate concentration and ventilatory threshold, researchers can examine the various parameters within the blood concentration and respiration in order to determine the critical exercise intensity at which an individual can exercise maximally for extended periods of time.

Traditionally, researchers have measured AT invasively by drawing blood samples; however, AT has been measured non-invasively through the use of ventilatory threshold analysis (Brooks, 1985; Wasserman, 1967). As proposed by Davis et al. (1985) and Wasserman et al. (1973), the departure in the linearity of the ventilation and the carbon dioxide (VCO_2), plus the abrupt increase in the gas exchange ratio (RQ), can be used as a marker for determining the onset on metabolic acidosis. Further, researchers concluded that there appears to be a systematic increase in the ventilatory equivalent for VO_2 (Ve/VCO_2) without a consistent increase in Ve/VO_2 (Caiozzo et al., 1982; Davis, 1985; Wasserman, 1978).

Researchers have used ventilatory parameters in the detection of VT since as early as 1964 (Wasserman, 1964). Several ventilatory measurements have been used to assess ventilatory threshold parameters including maximal oxygen consumption ($VO_{2\ max}$)(Bunc et

al., 1987; Haverty et al., 1988) minute ventilation (Ve)(Davis et al., 1976; Wasserman & Whipp, 1975) respiratory exchange ratio (RER)(Davis et. al, 1976; Wasserman and Whipp, 1976) excretion of CO_2 (VCO_2)(Beaver et al., 1986; Davis et al., 1976) and the use of the ratio of ventilation to maximal oxygen consumption (Ve/O_2) (Reinhard et al., 1979; Davis et al, 1979; Wasserman et al., 1981), and these measures have been suggested to correspond to anaerobic threshold. The most valid method currently used to non-invasivley measure VT is the V-slope method proposed by Beaver et al. (1986), which relies on the production of excess CO_2 generated from the buffering of metabolic acids produced during anaerobic metabolism. In this method, VCO_2 is plotted against VO_2. During the first portion of a graded exercise test using a cycle ergometer, the relationship between the two gas exchange variables is linear; however, at lactate threshold, VCO_2 begins to increase at a faster rate than VO_2, which results in the linear relationship when compared to blood lactate concentrations during progressive exercise determined that over 92% of the proton buffering is carried out by the bicarbonate buffering system (Beaver et al., 1986). Since the rate of excess CO_2 generated from this buffering system is dependent on the rate of lactic acid increase, the increased production of excess CO_2 closely estimates the increased dependence on anaerobic metabolism during exercise (Wasserman et al., 1996). Researchers have examined the relationship between blood lactate concentration and excess CO_2 production and reported correlations of .80 and .78 (Bouhuys et al., 1966; Anderson & Rhodes, 1990). Furthermore, in a study conducted by Hoogeven et al. (1998) results demonstrated that VT, using the V-slope method, was highly correlated with endurance performance in cyclists. The correlations in this study varied from .70 - .94, which correspond highly with previous studies (Coyle et al., 1988; Coyle et al., 1990; Craig et al., 1993; Lehmann et al., 1983).

In a study conducted by Simon et al. (1996) that examined plasma lactate and VT in trained and untrained cyclists, research revealed that VT and plasma lactate concentrations were similar. The trained subjects recorded significantly higher VO_2 values as compared to the untrained subjects, and the trained subjects' VO_2 at VT was significantly greater than the VO_2 at VT for untrained subjects. Results also indicated that an increase in plasma lactate, minute ventilation, and expired O_2 occurred together for trained subjects. Conversely, for the untrained individuals, the data revealed that the rise in minute ventilation and expired oxygen occurred before the rise in plasma lactate concentration. Furthermore, the recovery time of plasma lactate for the trained cyclists occurred sooner when compared to their

untrained counterparts (Simon et al., 1986). These finding were consistent with previously conducted studies regarding ventilatory threshold and plasma lactate concentration (Davis et al., 1976; Ivy et al., 1980).

Research has also shown that the anaerobic threshold (AT) plays a critical role in the assessment of athletic populations. Exercise physiologists use AT to monitor training adaptations (Ready & Quinney, 1982) and to prescribe various exercise protocols in an effort to elicit maximal aerobic performance (Whipp & Ward, 1980). The intensity of exercise at the AT is highly correlated with endurance activity (Costillet al., 1973; Farrell et al., 1979; Maffulli et al., 1991; Rheds & McKenzie, 1993) and is significantly related to an athlete's endurance capacity (Tanaka et al., 1983; Wettmar et al., 1978; Rusko et al., 1980). Therefore, the AT has gained acceptance as a critical determinant of optimal performance. For several decades, athletic performance was believed to be mainly attributed to an athlete's maximal O_2 consumption, however, with the recent research regarding AT, it has become clear that AT plays an important role in the performance of many athletes.

Although the use of ventilatory measures have been criticized in reference to the ability to accurately identify the anaerobic threshold, studies using ventilatory threshold have succeeded in identifying threshold intensities that are characteristic of prolonged exercise. Research conducted by Rhodes and MacKenzie (1984) used ventilatory threshold, characterized by a nonlinear increase in excess CO_2 production, to predict marathon performance from the velocity at which ventilatory threshold occurred during incremental exercise running velocity and therefore marathon times could be accurately predicted. Significantly high correlations existed between predicted and actual times; therefore, investigators were able to relate laboratory performances with actual field tests.

In the early eighties, Hearst et al. (1982) revealed that exercise at the velocity corresponding to VT produced significantly lower blood lactate concentrations than exercise 1.0 Km/h above ventilatory threshold which averaged 5.28 mmol/L. In addition, Kumangai et al. (1982) assessed both ventilatory threshold and $VO_{2\ max}$ measurements with various running distance and established that performance correlates higher with VT than with $VO_{2\ max}$.

Based on this research and previous research, investigators confirmed that AT, as measured using VT, is a more critical determinant of aerobic performance than aerobic capacity.

It has been suggested that the use of gas exchange dynamics may offer information for monitoring the physiological responses of athletes during training and during preparation for competition. The assessment of ventilatory threshold using this method, requires non-invasive, submaximal exercise testing, which has proved to be well received by coaches and athletes during training and competitive periods when maximal testing is contraindicated. In a study by Norris and Peterson (1997) in which VT was determined by gas exchange, results revealed that the time constant for oxygen uptake transition at various work levels was faster, $VO_{2\ max}$ increased and VO_2 at VT all lead to increases in cycling performance following an 8-week endurance training program. Of notable significance in this study was the fact that the ventilatory threshold increased significantly after only four weeks of endurance training.

2.4 Training Protocols

Training has been recognized as one of the main modifiers of physical performance. Numerous investigators have described the performance benefits of training and the underlying mechanisms. Physical training and subsequent conditioning does not alter the energy expenditure required to perform a given level of work; however, it does reduce the extent of cardiac and respiratory adaptation necessary to achieve the required rate of oxygen consumption (Faria, 1984). When planned carefully, the results of training will result in several broad metabolic and physical changes. One portion of this is the muscle fiber and metabolic changes that result from high intensity work of short duration, e.g. anaerobic work, including strength training. At the opposite end of the continuum are long term effects that result from prolonged bouts of work repeated many times at a sub maximal level, which promotes beneficial adaptations in central and peripheral aerobic capacity.

Current ideas on appropriate training regimens are largely based on subjective observations and experiences of coaches and athletes in the field. Sports physiologists have had a limited impact on the training practices of successful competitors (Wells & Pate, 1988).

One form of training used by endurance athletes is interval training (Wells & Pate, 1988). Such training employs sustained exercise bouts alternated with periods of slower paced activity or complete rest (Daniels & Scardina, 1984; Wells & Pate, 1988). Although such training is a basic element in athletic conditioning and is associated with improvements

in physical performance capacity (Wells & Pate, 1988), little is known about the rate at which physical changes occur in response to such training.

Early reports have shown that untrained individuals can increase their $VO_{2\ max}$ by 20 to 38% after 9 to 12 weeks of training (Hickson et al., 1981; Jones & McCartney, 1986). The largest increases in $VO_{2\ max}$ were observed in the elderly, whereas younger subjects showed smaller improvements. This may be related to the low initial $VO_{2\ max}$. Generally, a low $VO_{2\ max}$ at the onset of training results in large improvements after training, whereas high initial $VO_{2\ max}$ values result in smaller increases. Unfortunately, $VO_{2\ max}$ is not always a good indicator of exercise performance, and therefore, it can be difficult to predict performance improvements from these studies. It is likely, however, that these training programs resulted not only in an increased $VO_{2\ max}$ but also in a significant shift of the lactate threshold.

Several studies have been conducted in moderately trained and trained athletes. Norris & Petersen (1998) investigated the effect of an 8-week training program (5 times/week, 40-55min) on the performance of 16 competitive cyclists ($VO_{2\ max}$ 57 ml/kg/min). Performance was evaluated with a $VO_{2\ max}$ test and a simulated 40 km time trial after four and eight weeks. Performance improvements were observed within four weeks, and by the end of the eight weeks of training $VO_{2\ max}$ had improved by 5% and the 40 km time was reduced by 8.4%.

Westgarth-Taylor et al.(1997) investigated the effects of a modified training regimen in eight cyclists ($VO_{2\ max}$=64 ml/kg/min). A total of 15% of their endurance training was replaced by high intensity training. After six weeks, peak power (Wmax) was increased from 404+/-40W to 424+/- 53W (5.0%) and time to complete 40 km was 2.4% less. During the time trial cyclist averaged 327+/- 51W after training, compared with 291+/- 43W before (11.3%). They not only performed at a higher absolute workload but also at a higher relative intensity (8.1 vs 72.6% Wmax), possibly indicating a shift in lactate threshold. Similar results were obtained by the same research group when participants trained in a similar manner for 4 weeks (Lindsay et al., 1996). Wmax was increased 4.3% and the 40 km time was improved by 3.5%.

Stepto et al. (1999) studied the effects of five different interval training protocols in 20 trained cyclists (VO_2max 61.3 ml/kg/min). Cyclists completed 6 interval sessions in 3 weeks, and before and after the training period, Wmax and 40 km time trial performance

were measured. The interval training protocols ranged from 12, 30 second intervals at 175% Wmax to 4, 8 minute intervals at 80% Wmax. The most profound changes in performance (2.4% increase in Wmax and 2.3% improvement in 40 km time trial performance) were observed with a protocol consisting of 8, 4 minute intervals at 85% Wmax with a 1.5min rest between each interval.

Although little or no data are available on the effects of training in already highly trained cyclists, (Jeukendrup & Van Diemen, 1998) anecdotal evidence suggests that improvements in performance are small, despite significant increases in training volume and intensity.

Elite cyclists are known to posses a moderately high oxygen uptake capability. During competition the cyclist's oxygen transport system's are loaded maximally (80-85% $VO_{2\ max}$). Therefore, a major portion of the training program should aim to improve the determinants of oxygen transport and uptake.

If the oxygen transport and use systems are to be trained, they must be overloaded. To achieve overload, the training tempo must be high. Lactic acid concentration is likely to build in the muscles when a high tempo is sustained for extended periods. A reduction in tempo is created by lactate accumulation, which serves to reduce the load on the heart, lungs and enzyme producing systems. Alternating between hard and easy tempos can, to a certain extent, counteract the increase in lactic acid while still overloading the system. Various forms of interval training may be employed in order to achieve this.

To overload the oxygenating enzymes in slow twitch muscle fibers, intensity should be kept below race pace. Work intervals should range between 70 to 80% of heart rate max with short recovery periods. An example of this could be 20 repeats of 800m sprints with 30 seconds rest between (Faria, 1984). The objective of this particular training procedure is enhancement of the work capacity of slow twitch muscle fiber. The expected outcome would be an increase in the number and size of mitochondria, improved enzyme activity, enhanced fat metabolism and improved oxygen delivery. It is this type of training which will build an essential foundation upon which future endeavors will rely upon (Faria, 1984). Training sessions may last 2 to 4 hours. As progress is made, the length and number of work intervals should be increased. Effective recruitment of muscle fibers may be achieved by sustained pedaling at 90 to 100 rpm (Faria, 1984).

Along with aerobic training, some portion of the training schedule must be devoted to raising the anaerobic threshold. The purpose of such training is to recruit fast oxidative glycolytic muscle fibers. By training these specific fibers, the cyclist should be able to compete at a higher percentage of maximal oxygen uptake.

To maximize involvement of these fast oxidative glycolytic fibers, the training intensity must be held at 90% of maximal heart rate. Heart rate should not be more than 10 beats below its maximum at the end of each work interval. Due to the difficulty of sustaining such a high intensity, it is recommended that interval training be used.

The objective of such a training program is to improve the muscles' supply of adenosine triphosphate (ATP) and creatine phosphate (CP) as well as enhance the ability of the glycolytic pathway to produce ATP anaerobically. Training intensity must remain high in an effort to recruit fast twitch fibers, specifically fast glycolytic fibers. Cyclist utilize this type of training in an effort to improve performance in starts, hill climbing, breakaways and sprint finishes.

Work intervals of 60 to 90 seconds, interspersed with 20 to 30 second recovery intervals are recommended. Results may be achieved with 8 to 12 repetitions and an active recovery interval twice that of the work interval. Not more than 2 to 3 training sessions per week of this training type should be undertaken (Faria, 1984). Shorter work intervals of 10 to 20 seconds, with 5 to 15 second periods of active recovery, continued for a total of 20 to 60 minutes are designed to tax the high-energy supplies in the muscles.

During a training program, the initial changes in the physiological responses to repeated exercise have been shown to be due to readjustments in the central circulatory control (Faria, 1984). The redistribution of cardiac output is in favor of the active muscles. The initial effects of a training program are reflected by two responses. The first is a marked change in the cardiovascular response to exercise without a concomitant change in maximal aerobic power ($VO_{2\ max}$). A second response is a slow decline in cardiac frequency for a given oxygen uptake. Where relatively large muscle groups are used, as in cycling, the limiting factor for work is the cardiovascular system's ability to transport the necessary blood volume, not the muscles' capacity to utilize oxygen.

An individual's natural ability differs in relation to skeletal muscle mass, heart size and muscle fiber composition; to the extent that training programs must be individually prescribed to meet specific goals. Therefore, it would appear that at this time sport scientists

are unable to determine what one form of training is best for elite cyclists. Most racers use distance training, interval training, sprint and climbing training. The ideal ratio of interval to distance training has also yet to be been defined.

Chapter 3. Methodology

3.1 Subjects

A total of 10 amateur, well-trained cyclists between the ages of 25 and 37 years have served as subjects. For all subjects over 30 years of age, a qualified medical doctor was present during the GXT in accordance with the regulations of the Institutional Review Board. Subjects were free of known disease, and all subjects with known disease were be excluded from the study. Individuals with any acute medical conditions, active infection, or taking cardiovascular medications were excluded from the study as well.

Ability levels for the 10 cyclists ranged from United States Cycling Federation (USCF) track classification of category 4 and 5 riders. Cyclists were asked to participate in only a light recovery session (less than 50 Km at less than 75% HRM) before any testing session (pre-test & post testing). All subjects were informed of the purpose of this study and the risks associated with this study, in accordance with the standards of the Institutional Review Board at Louisiana State University.

3.2 Experiment Protocol

3.2.1 Screening and Orientation

All potential subjects for the study were recruited from the Baton Rouge area and were required to complete a PAR-Q questionnaire as required by the Institution Review Board. Those individuals who have no contraindications were asked to volunteer for this investigation. All individuals received a comprehensive explanation of the proposed study, the benefits associated with participation in the study, the inherent risks, and the expected time commitment. Following a formal explanation of the proposal, all individuals were further instructed about the clothing necessary to participate in the pre and post testing, as well as the 4 week training protocol.

3.2.2 Visit #1: (V1)

Subjects in this investigation were scheduled for an initial visit at the Center for Exercise Science at Louisiana State University. Upon arrival at the center, participants were asked to read and sign an informed consent document, as well as complete dietary and quality of life questionnaires. Subsequently, anthropometric measures, body composition

and a maximal exercise test on a cycle ergometer will be performed to determine initial $VO_{2\,max}$, anaerobic capacity and performance (MAOD, VT).

3.2.3 Visit #2: (V2)

Upon completion of V1, each subject was asked to return within one week for a Wingate test to determine initial power output. Following the completion of the Wingate test, subjects participated in a track training session at the Baton Rouge Recreation and Park Commission (BREC) Velodrome in Baton Rouge, LA. During this second visit, subjects were introduced to the track and had a fixed gear track bicycle fitted to their body size.

Seat height for each subject was adjusted so that the subject's knee was slightly bent when the ball of the foot is on the pedal. Saddle fore/aft positioning was set based in accordance with a plumb line dropped from behind the posterior aspect of the subject's patella bisecting the forward pedal axle, while both crank arms are parallel to the floor. Saddle tilt was adjusted to rider comfort. Saddle height as well as fore/aft position was recorded for each subject.

3.2.4 Visit #3: (V3)

Subjects were asked to arrive at the velodrome 2-4 days after V2. During this visit, subjects were tested for 4000m Individual Pursuit (4000m IP) capabilities; therefore, all subjects will have performed a 4000m IP in accordance with the previously outlined protocol. The 4000m IP was performed on a 333m, concrete, outdoor velodrome with 32° embanked walls. Subjects were required to wear cycling shorts, a sleeved jersey, as well as a SNELL Memorial Foundation approved cycling helmet. Performance time and average speed was measured, as well as average cadence, maximum cadence and maximum speed.

3.3 Track Testing

A timed, standing start 4000m IP was completed by each subject on two separate occasions, pre and post training testing. Each subject was individually fitted to a fixed gear track bicycle, equipped with aerobars and a shoe-pedal retention system. Each subject wore appropriate cycling attire and a SNELL Memorial Foundation approved cycling helmet. Subjects were allowed to use a cyclo-computer as an indicator of current and average speed in an effort to aid in pace setting.

The 4000 m individual pursuit consisted of 12 complete laps around the velodrome. Subjects were informed of the number of laps remaining within the 4000m IP by the use of

two-way radios and earpiece speakers. Each subject was told the number of laps remaining, with a bell being rung to indicate when the subject had only one lap remaining. Heart rate was measured continuously during the 4000m event for the determination of maximal and average values using a Sigma Sport PC 14 heart rate monitor.

3.4 Anaerobic Capacity

Anaerobic Capacity was assessed as maximal accumulated oxygen deficit (MAOD) in accordance to the procedures outlined by Medbo et al. (1998) during 2-and 5-minute supramaximal cycling protocols.

During the test, the work performance of the subjects was recorded every 10 seconds. The O_2 requirement for the mean power output for each 10s period was predicted by linear extrapolation of the individual relationship between VO_2 and submaximal power output as proposed by Van Hardel et al. (1988). Subtraction of the VO_2 during the test for O_2 requirements will yield a predicted O_2 deficit. Heart rate was measured using an earpiece pulse monitor connected to a Computainer electronic bicycle ergometer running it's coaching software. Each subject was asked to complete the test for MAOD on two separate occasions (as part of the $VO_{2\ max}$ testing), prior to and after the 4-week training protocol as described previously.

3.5 Measurement of $VO_{2\ max}$

Sensor Medics Vmax pulmonary gas exchange system was used to evaluate each subject's maximal oxygen consumption. All VO_2 measurements were determined using breath-by-breath analysis during a continuous incremental cycling protocol lasting 8-12 minutes. Expired gas measurements were continually monitored for O_2 and CO_2 concentrations. A mouthpiece with a flow sensor was attached to the Vmax system and inserted into the subjects mouth to sample expired air. A time delay factor was used to align inspiratory gas volumes and expiratory gas analysis. All gas analyzers were calibrated before each test using the calibration techniques described by Sensor Medics system protocol.

Maximal oxygen uptake ($VO_{2\ max}$) was determined using a continuous incremental cycling test performed on a fixed-gear track bicycle attached to an electronically braked cycle ergometer, Computrainer Pro 3D. The warm-up period was standardized; instead,

subjects were asked to prepare for the test as they would prepare in readiness for an actual competition.

After completion of the warm-up phase, the subjects were required to pedal at a constant intensity for 1 minute, following the incrementally increasing resistance profile of the Frielman course included in the Computrainer coaching software. The participants pedaled until exhaustion. The cycling protocol required cadence to be maintained at a rate above 90 rpm. Metabolic and heart rate data was measured every 20 seconds, as was total work output.

$VO_{2\ max}$ was assessed on two separate occasions: pre-training and after the 4-week training protocol.

3.6 Anaerobic Threshold

Anaerobic threshold was determined for each subject through the use of ventilatory threshold analysis as proposed by Wasserman et al. (1973). The ventilatory gas exchange threshold was determined as the VO_2 at which the ventilatory equivalent for O_2 (Ve/VO_2) displayed at a systematic increase in Ve/VeO_2. This criterion has been reported to be the most sensitive indication of ventilatory threshold (VT) (Davis et al., 1983; Davis et al., 1979; Wasserman et al., 1973). Each VT measure was determined by the breath-by-breath analysis and computer print out for the ventilatory equivalent for O_2 and CO_2 as a function of VO_2.

Each subject's anaerobic threshold was tested on two occasions, prior to and following the 4-week training session.

3.7 Power Output

Maximal power output was derived using a 333m standing start sprint, performed on a fixed gear bicycle attached to a Computrainer Pro 3D cycle ergometer. The subjects were exercised maximally in a simulated first lap of a 4000m IP against a resistance equivalent to that in which the riders would experience on a velodrome surface. The resistance experienced was generated by the Computrainer cycle ergometer, using load calculations generated using subject weight.

The subject were asked to begin a warm-up session, lasting 3-6 minutes at an intensity appropriate to elevate heart rate to 150-170 bpm. After the warm-up period, each subject was asked to rest for 3-6 minutes. Following the rest period, the participant began pedaling their bicycle as fast as they were capable. Power output, both maximal and average were recorded in real time as well as pedal cadence, elapsed time, heart rate and speed. These measures were all examined and recorded via the Computrainer coaching software being run on a Dell laptop computer attached to the Computrainer cycle ergometer.

Immediately upon completion of the test, each subject was asked to cool down for 3-6 minutes on the Computrainer cycle ergometer at a minimal resistance level. Each subject performed this test on 2 occasions, pre-and post-training.

3.8 Training

During the 4-week training program, the subjects trained approximately 75 minutes/day for 3 days/week at a work rate of 60-80% heart rate max for group #2 and 85-100% of heart rate max for group #1.

The training protocol for group #1 was initially based on the data collected from the initial 4000m IP performed during V3 (average speed). Each week's training protocol consists of 3 training days.

Throughout the 4-week training session, days 1 & 2 were comprised of sprints of increasing length each week and multiple 1000m time trials. The third day of each training session consisted of 3 4000m IPs. The 1000m time trials were all performed at each subject's maximal performance capacity.

3.8.1 Group 1

Week #1: Each subject performed eight 166m sprints from a stationary start with 5 minutes of active recovery intervals between each attempt (2-3000m). Each active recovery period consisted of slow but constant pedaling on a fixed gear track bicycle, which allowed each subject's heart rate to return to near baseline. Subjects also performed five 1000m time trials with 5 minute active recovery intervals between each attempt. Each 1000m TT was performed at maximal capacity at the end of the first two days training sessions each week.

Week #2: Each subject performed six 333m sprints from a stationary start with 4 minutes of active recovery intervals between each attempt. Subjects also performed five 1000m time trials with 5 minutes of active recovery intervals between each attempt

Week #3: Subjects performed four 500m sprints from a stationary start with 5 minutes of active recovery intervals between each attempt. Subjects will also perform five 1000m time trials with 5 minutes of active recovery intervals between each attempt.

Week #4: Each subject performed two 666m sprints from a stationary start with 6 minutes of active recovery intervals between each attempt. Subjects also performed five 1000m time trials with 5 minutes of active recovery intervals between each attempt.

3.8.2 Group 2

Each subject followed a three-day per week training regimen, unique from that of group #1. Throughout the 4 week training session, days 1 & 2 were comprised of multiple time trials performed at 70 & 80% of heart rate max achieved during the 4000m IP of the previous week. Each time trial was followed by an active recovery period that varied in length between 5 and 8 minutes. The third day of each training session required the subjects to perform three 4000m IPs. The highest HR achieved during the three 4000m IPs was used as the basis for the required HR in the following week's time trials, which were be performed at 70 & 80% of that max HR.

Week #1: Day #1: Each subject performed three 6000m TT from a stationary start performed at 80% HRmax with 5 minutes of active recovery intervals between each attempt. Subjects also performed two 10000m time trials at an intensity of 70% HRmax with 5 minutes of active recovery intervals between each attempt. Day #2: Each subject performed 3 6000m TT from a stationary start performed at 80% HRmax with 8 minutes of active recovery intervals between each attempt. Subjects also performed two 10,000m time trials at an intensity of 70% HRmax with 5 minutes of active recovery intervals between each attempt.

Week #2: Day #1: Subjects performed three 8000m TT from a stationary start performed at 80% HRmax with 5 minutes of active recovery intervals between each attempt. Each subject also performed two 12000m time trials performed at 70% HRmax with 5 minutes of active recovery intervals between each attempt. Day #2: Each subject performed three 8000m TT from a stationary start performed at 80% HRmax with 5 minutes of active recovery intervals between each attempt. Each subject also performed two 12000m time trials at 70% HRmax with 5 minute active recovery intervals between each attempt.

Week #3: Day #1: Subjects performed two 10000m TT from a stationary start performed at 80% HRmax with 8 minutes of active recovery intervals between each attempt.

Each subject also performed one 14000m TT performed at an intensity of 70% HRmax. Day #2: Subjects performed two 10000m TT from a stationary start performed at 80% HRmax with 8 minutes of active recovery intervals between each attempt. Each subject also performed one 14000m time trial at an intensity of 70% HRmax.

Week #4: Day #1: Subjects performed two 12000m TT from a stationary start performed at 80% HRmax with 8 minutes of active recovery intervals between each attempt. Each subject also performed one 18000m time trial at an intensity of 70% HRmax. Day #2: Subjects performed two 12000m TT from a stationary start performed at 80% HRmax with 8 minutes of active recovery intervals between each attempt. Each subject also performed one 18000m TT at an intensity of 70% HRmax.

3.9 Statistical Analysis

Descriptive statistics were performed on the group data using standard statistical procedures. Means and standard deviations were determined for the post-training changes in $VO_{2\ max}$, ventilatory threshold, average and maximum power output, MAOD, and 4000m IP performances for each protocol. A two-sample independent T-test was used to compare if the mean changes in $VO_{2\ max}$, ventilatory threshold, average and maximum power output, MAOD, and 4000m IP performance were statistically different between the sprint and distance protocols. A standard one-sample student T-test was used to determine if there were significant differences in $VO_{2\ max}$, ventilatory threshold, maximum and average power output, MAOD, and 4000m IP performances before and after the 4-week training period for each protocol. The significance level was set at $\alpha<0.05$ for all testing. A regression analysis was then used to determine if improvements in 4000m IP could be predicted based on improvements in $VO_{2\ max}$, ventilatory threshold, average and maximum power output, and MAOD. A stepwise procedure was used to determine the best possible combination of regressions. All analyses were performed using SAS.

Chapter 4. Results and Analysis

Standard descriptive statistics were first determined for pre-and post-training measures of 4000m time, MAOD, $VO_{2\,max}$, VO_2 @ VT, Max power, and Average power within each training protocol. Means and standard deviations for each variable within each training protocol are given in Table 4.1.

Table 4.1
Mean and Standard Deviation, Pre-and Post-training Variables of Interest

Distance Protocol	Pre-training		Post-training	
	Mean	*Stdev*	*Mean*	*Stdev*
4000m time	413.26	28.52	384.74	19.52
MAOD	420.07	46.80	509.14	141.66
$VO_{2\,max}$	49.82	4.73	60.20	15.86
VO_2 at VT	45.31	4.03	51.65	8.20
Max power	852.40	188.45	833.00	191.69
Average power	614.80	231.96	628.60	224.69

Sprint Protocol	Pre-training		Post-training	
	Mean	*Stdev*	*Mean*	*Stdev*
4000m time	419.64	15.45	384.02	30.45
MAOD	430.09	100.94	456.97	87.53
$VO_{2\,max}$	48.20	5.23	54.00	6.89
VO_2 at VT	40.91	2.97	45.00	7.27
Max power	767.80	199.11	815.20	172.49
Average power	499.40	126.20	545.40	95.11

Let Δ4000m time, ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power represent the post-training changes for 4000m performance, MAOD, $VO_{2\,max}$, VO_2 @ VT, Max power, and Average power, respectively. Normality tests were run on the variables of interest (Δ4000m time, ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power). Due to the small sample size, the Shapiro–Wilk test was used. The tests

indicated that when samples were collapsed over treatments there was a failure to reject the normality assumption for ΔMAOD, ΔVO_2 @ VT, ΔMax power, and ΔAverage power. Since there is not sufficient evidence to clearly reject normality for these variables, it is assumed that they are approximately normally distributed. This assumption cannot be made for Δ4000m time and $\Delta VO_{2\,max}$. The Shapiro-Wilk test was then run on each of the same variables, but separated by treatment. Results of these tests indicate a failure to reject normality for Δ4000m time, ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power for the distance protocol, and for ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power for the sprint protocol. Again, it is then assumed that these variables are normally distributed. It cannot be assumed that Δ4000m times for the distance protocol is normally distributed.

A two-sample independent t-test was used to test if the mean improvements in 4000m time, MAOD, $VO_{2\,max}$, VO_2 @ VT, Max power, and Average power for the sprint trained group differ from the mean improvements in the distance trained group. Assumptions for this test are that within each sample, observations are independent and identically normally distributed, and that the two samples are independent of each other. The usual two-sample t-test assumes that the two samples come from populations with the same variance, allowing for a pooled estimate of the variance to be used. However, if the two sample variances were clearly different, the Welch-Satterthwaite t-test was used instead.

The normality test results indicated that ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power were normally distributed in both protocols. Only Δ4000m time was not normal for each protocol. However, Stonehouse and Forrester (1998) found the two-sample independent t-test to be fairly robust with sample sizes as small as five, so long as the sample sizes were equal for each sample and the variances were also equal. An F-test for the equality of variances indicated that the variances were the same for Δ4000m times within each group, and thus the standard two-sample t-test was used. The mean and standard deviation of the mean post-training changes in the variables of interest are given in Table 4.2, along with the p-value for the t-test.

Table 4.2
Mean and Standard Deviation of the Mean Post-training Change

	Mean	Std Dev	Mean	Std Dev	P value	Significant 0.05 level
Variable	**Sprint Protocol**	**Sprint Protocol**	**Distance Protocol**	**Distance Protocol**		
Δ4000m time	-35.62	21.7818	-28.52	12.47546	0.5447	No
ΔMOAD	26.878	36.17856	89.07	118.1754	0.3142	No
$\Delta VO_{2\ max}$	5.8	3.931285	10.38	13.30553	0.4956	No
ΔVO_2@VT	4.088	4.391101	6.342	4.694648	0.4556	No
ΔMax power	47.4	43.7984	-19.4	71.12173	0.1115	No
ΔAve power	46	39.50316	13.8	57.53868	0.3324	No

The results of the t-test indicate that for each of the variables there were no statistically significant (0.05 level) differences between the two training protocols.

Because no significant differences were found when comparing both groups, a one sample T-test was next used to examine changes within each protocol. The results for these tests are given in Table 4.3.

Table 4.3.1
One Sample t-Test results for Distance protocol.

Variable	P-value	Significance @. 05?
4ktime	.0069	Yes
MOAD	.1672	No
$VO_{2\ max}$	.1560	No
VO_2@VT	.0391	Yes
Max power	.5749	No
Ave power	.6202	No

Table 4.3.2
One sample T-test results for Sprint protocol.

Variable	P-value	Significance @. 05?
4ktime	.0216	Yes
MOAD	.1720	No
$VO_{2\ max}$	.0300	Yes
VO_2@VT	.1058	No
Max power	.0728	No
Ave power	.0598	No

For the distance group a significant difference was found in both 4000m time and VO_2 @ VT. For the sprint group a significant difference was found in both 4000m time and $VO_{2\,max}$. Max power and Average power, although not significant at the 0.05 level, were found to be significant at the 0.10 level for the sprint group.

A stepwise regression was then used to determine if changes in 4000m performance could be attributed to changes in measured variables that have shown statistical significance. SAS was used to run the forward stepwise regression analysis with Δ4000m times as the dependent variable and $\Delta VO_{2\,max}$, ΔMax power, and ΔAverage power as the potential independent variables for the sprint protocol. Variables were added to the model if the calculated F statistic was significant at the 0.1500 (SAS default). No variables were found to be significant enough to enter the model. The procedure was repeated for the distance protocol using Δ4000m time as the dependant variable and ΔVO_2 @ VT as a potential independent variable; however, ΔVO_2 @ VT was not significant enough to enter the proposed model. As a result of the forward stepwise regression analysis, it was determined that improvements in 4000m performance could not be attributed to any particular variable in either training protocol.

Although the original intent of the research was to examine whether improvement in 4000m performance could be attributed to one training method over another, the inability to confirm that possibility led to the concept of examining the data as a combined sample. The two samples were collapsed over treatment, and a one-sample t-test was used to determine if there was a significant mean improvement after training in each of the following measures: Δ4000m time, ΔMAOD, $\Delta VO_{2\,max}$, ΔVO_2 @ VT, ΔMax power, and ΔAverage power, provided that a few assumptions were met. The standard t-test assumptions are that each observation is independent and that the sample was drawn from a normally distributed population. In cases where normality is violated, nonparametric tests may be more appropriate. For Δ4000m time and $\Delta VO_{2\,max}$, the normality assumption is violated, but the t-test is fairly robust even with non-normally distributed data (PROPHET Stat Guide). The sign test, a nonparametric alternative to the t-test, was also investigated for these variables as well, but did not yield different results. The mean and standard deviation of these mean post-training changes are given in Table 4.4, along with the p-value for the t-test.

Table 4.4
Mean and Standard Deviation of Mean Post-training Changes

Variable	Mean	Standard Deviation	**P value**	**Significant** At 0.05 level
Δ4000m time	-32.07 s	17.1476	**.0001**	***Yes***
ΔMAOD	57.974	88.67347	**.0343**	**Yes**
$\Delta VO_{2\ max}$	8.09 L/Kg/min	9.559225	**.0127**	**Yes**
ΔVO_2 @ VT	5.215 L/Kg/min	4.447062	**.00245**	**Yes**
ΔMax power	14 W	65.88036	**.25925**	**No**
ΔAvg. power	29.9 W	49.52766	**.0443**	**Yes**

Significant improvements were found for all variables except ΔMax power. Statistically, differences were not found when comparing groups; individually, both training protocols elicited significant improvements in Δ4000m times, ΔMAOD, $\Delta VO_{2\ max}$, ΔVO_2 @ VT and ΔAvg. power.

The next analysis was to determine whether improvements in 4000m performances could be attributed to improvements in other variables, namely MOAD, $VO_{2\ max}$, VO_2 @ VT, Max power, and Average power. SAS was used to run the forward stepwise regression analysis with Δ4000m times as the dependent variable and ΔMAOD, $\Delta VO_{2\ max}$, ΔVO_2 @ VT, Δmax power, and Δaverage power as the potential independent variables. Variables were added to the model if the calculated F statistic was significant at the 0.1500 level (SAS default). The procedure required only three steps and the results of each step are shown in Table 4.5.

Table 4.5
Forward Stepwise Regression Analysis

Step	Variable Entered	Number of Variables in Model	F	P-value
1	Average power	1	6.97	.0297
2	MAOD	2	2.80	.1379
3	VO_2 @ VT	3	3.08	.1300

Then the resulting regression model can then be written as follows:

$$\Delta 4000mTime = -22.02513 + 0.13086^* \Delta MAOD - 1.73780^* \Delta VO_2 @ VT - 0.28658^* \Delta Average\ power$$

Regression results including parameter estimates and p-values are given in Table 4.6.

Table 4.6
Regression Results

Variable	Parameter Estimate	Standard Error	F Value	P-value
Intercept	-22.02513	5.78661	14.49	0.0089
ΔAverage power	-0.28658	0.07359	15.17	0.0080
ΔMAOD	0.13086	0.05075	6.65	0.0418
ΔVO_2 @ VT	-1.73780	0.99084	3.08	0.1300

The above parameter estimates indicate that an improvement in 4000m performances can be attributed to changes in Average power, MAOD, and VO_2 @ VT. The coefficient of multiple determinations, R^2, has a value of 0.7478. This indicates that changes in average power, MAOD, and VO_2 @ VT explain 74.78% of the variability in Δ4000m performances. The marginal changes in 4000m performance times due to changes in each of the regression variables are given by the parameter estimates. An increase in average power of 1 watt contributes to an improvement in 4000m times of .28658 seconds, holding the other variables constant. An increase of 1 unit in MAOD will slow 4000m times by .13086 seconds, holding all other variables constant. An increase of 1 unit in VO_2 @ VT contributes to a 1.73780 second improvement in 4000m times, holding the other variables constant.

4.1 Discussion

The purpose of this research was to determine which of two training methods for improving an amateur competitive cyclist's performance in the 4000m individual pursuit time trial is most effective. Through development and selection of a very specific population of test subjects and use of a 4-week training period, the expectation for improvement was significant; though statistically utilizing a small sample size stood to indicate otherwise.

Improvements in performance were the primary focus of the current research program. Eleven subjects participated in the training program, and were divided into two unique training protocols. Ten of the eleven subjects completed the entire training and testing portions of the program resulting in two equal groups; five subjects in each training protocol.

The concept of using training programs that focused solely on either aerobic or anaerobic pathways was done in an effort to determine whether it would be beneficial to concentrate on training one particular pathway over the other. Various performance and metabolic measures were recorded before and after training for each subject. These measure were to be used to determine if adaptations experienced as a result of either training protocol could be identified as having a significant influence on changes in 4000m time trial performance. MAOD, $VO_{2\,max}$, VO_2 @ VT, Max power, and Average power were the variables chosen, as their influence on cycling performance and specifically 4000m time trial performance have been noted in prior research.

As indicated by the data collected during the course of this study, there does not appear to be enough evidence to indicate that either the anaerobically emphasized sprint training protocol or the aerobically emphasized distance training protocol elicited performance changes that could be identified as the more advantageous training method. Due in part to small sample sizes and the great similarity between those subjects, this situation was not completely unexpected. Though it seems that neither of the training protocols was superior to the other, each did result in improvements in 4000m time trial performance. Not only did each training protocol yield performance gains, but, by examining the changes observed within each of the physiological variables recorded, the specific effects of each protocol can be identified.

4.1.1 4000m

Each subject's performance in the 4000m individual pursuit time trial was the most important outcome variable of the current research. In an event where at the Olympic level, performance is measured in thousandths of a second and even hundredths of a second in local competitions, even the smallest improvements are sought. For this particular program, subjects were provided with a fixed gear bicycle equipped with handlebars that offered the subject a more aerodynamic riding position. The configuration of each rider's equipment was evaluated at each training session in an effort to maintain optimal performance and reduce injury. Each subject completed their training protocol, performance measures and metabolic testing using the same bicycle configuration, gear ratio and tire selection as was pre-determined before the study began, in an effort to maintain the accuracy of the measures.

As a result of the training, 4000m time trial performance improved in each instance. The sprint group experienced a mean improvement of 8.54% in their 4000m time trial performance. The distance group experienced a mean improvement of 6.79% in their 4000m time trial performance. The degree of change within each individual training method was found to be statistically significant at the 0.05 level, though the difference between the two was not. Power calculations were made for individual subject's performance change; at an $\propto$ of .01 a power measure of .055 was found, while an $\propto$ of .02 the power was found to be .0697 .

From a competitive perspective the difference between the two training protocols, however, might be noteworthy, and deserves further study. Individual 4000m performance improvements are noted in Tables 4.7 and 4.8.

Table 4.7

4000m Performance Change, Distance Protocol

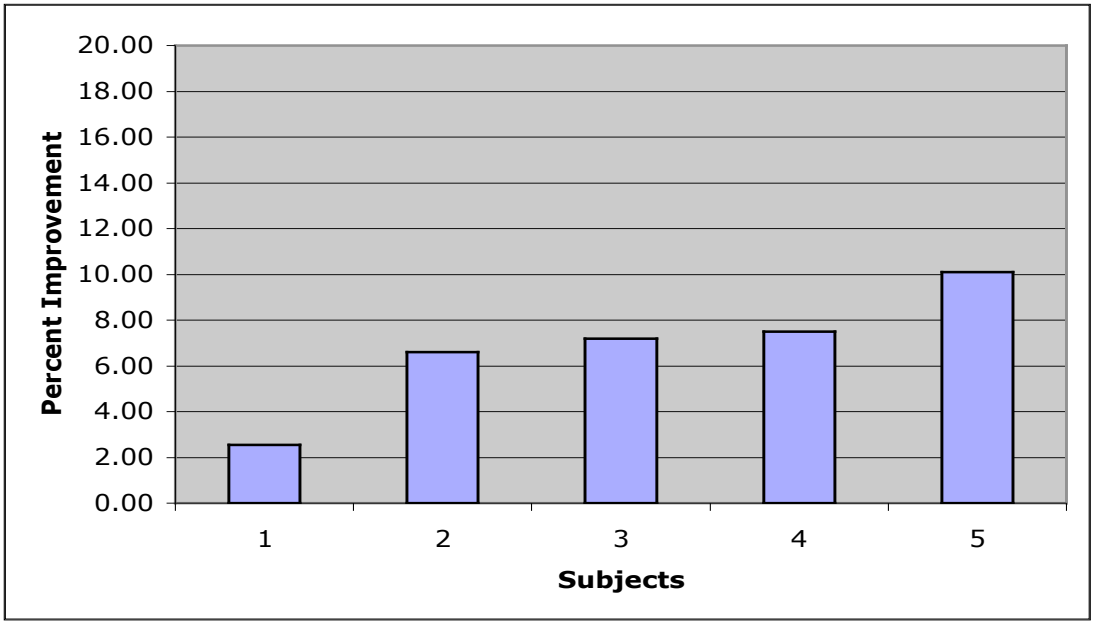
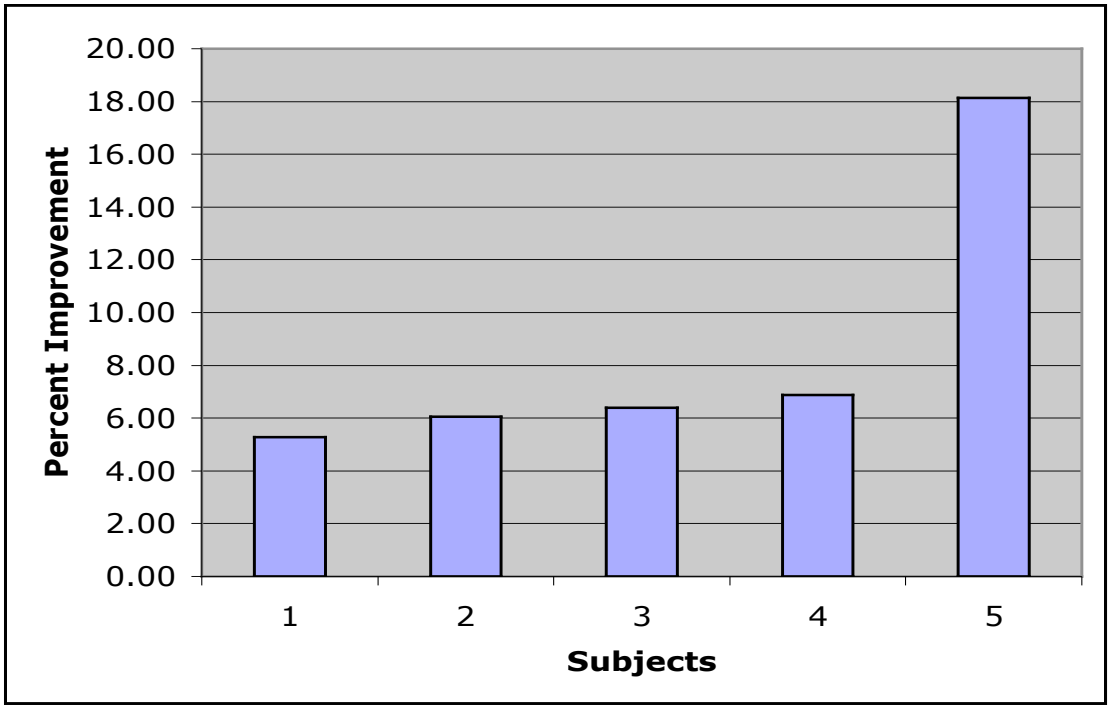


Table 4.8

4000m Performance Change, Sprint Protocol



4.1.2 $VO_{2\ max}$

The findings of this research indicate that only the sprint group experienced a significant change in $VO_{2\ max}$, which lends credibility to high intensity training's ability to improve maximal oxygen consumption within a four-week period. Pre-training VO_2 values for this program began at 49.8 mL/Kg/min and 48.2 mL/Kg/min, for the distance and sprint protocols respectively. Following the 4-week training protocols, $VO_{2\ max}$ was elevated to 60.2 mL/Kg/min and 54.0 mL/Kg/min for the distance and sprint groups. These findings first indicate the similarity between all participants at pre training, and are in keeping with those measures recorded for elite cyclists. The average values for $VO_{2\ max}$ for elite cyclists range from 69.1 mL/Kg/min to 74 mL/Kg/min. Two test subjects achieved $VO_{2\ max}$ values that fall into this range, 80.7 mL/Kg/min and 71.4 mL/Kg/min, each of which were members of the distance group. This data suggests that moderately high oxygen uptake capacities are required for successful competition.

According to Craig et al. (1993), $VO_{2\ max}$ was significantly correlated with individual 4000m track performance, that was not the case here, as $VO_{2\ max}$ was not found to significantly correlate to 4000m performance. Moreover, the subject with the fastest 4000m

performance did not have the highest $VO_{2\ max}$. Nevertheless, $VO_{2\ max}$ did increase for all subjects, as did their 4000m performances, which is in keeping with previous findings.

Several studies have been conducted with moderately trained and untrained athletes. Jeukendrup et al (2001) revealed that novice cyclist, with a relatively short history of cycling training, demonstrate a 20-38% increase in $VO_{2\ max}$ after a 9-12 week training program. Norris & Petersen (1998) investigated the effect of an 8-week training program (5 times/week, 40-55min) on the performance of 16 competitive cyclists ($VO_{2\ max}$ 57 ml/kg/min). In that study, performance improvements were observed within four weeks, and by the end of the eight weeks of training $VO_{2\ max}$ was improved by 5%. In the research conducted as part of this study, the combined results of the distance and sprint groups reveal a 7.67% mean improvement in $VO_{2\ max}$ after completing the four weeks of training. The gains experienced by the subjects in this training program are in keeping with those that have been found previously, though these are higher than those found by Norris & Petersen (1998).

4.1.3 Ventilatory Threshold

Having experienced increases in $VO_{2\ max}$ within each training protocol, ventilatory threshold (VT) can be used to further specify the areas of change that could be attributed to the improvements experienced in 4000m performance. VT was determined utilizing the V-slope method proposed by Beaver et al. (1986), which relies on the production of excess CO_2 generated from the buffering of metabolic acids produced during anaerobic metabolism, correlating performance gains to a single measurement variable was attempted.

Although the use of ventilatory measures have been criticized in reference to the ability to accurately identify the anaerobic threshold, studies using ventilatory threshold have succeeded in identifying threshold intensities that are characteristic of prolonged exercise. VO_2 @ VT for the distance and sprint groups were found to be 45.31 mL/Kg/min and 48.20 mL/Kg/min respectively. Following each group's training programs, VO_2 @VT had increased to 51.7 mL/Kg/min and 45.0 mL/Kg/min, with the distance group retaining the higher values. Between the two training programs, only the distance group exhibited a significant change in their VO_2 @ VT. These findings reflect the influence of training duration on the measure. Though the mean change between each group was small, 4.1 mL/Kg/min (sprint) versus 6.3 mL/Kg/min (distance), the prolonged duration of the

intervals (@ 80% HRmax) within the distance program could be attributed to the greater change over the sprint group.

A study conducted by Simon et al. (1996) examining plasma lactate and VT in trained and untrained cyclists, revealed that VT and plasma lactate concentrations were similar. The trained subjects recorded significantly higher VO_2 values as compared to the untrained subjects and the trained subjects VO_2 @ VT was significantly greater than the VO_2 at VT for untrained subjects. Through combining the two groups from the present study, VO_2 @ VT was found to have significantly changed within the four-week training programs. The mean improvement for the combined groups was 5.2 mL/Kg/min and was highly correlated to 4000m performance. Using a stepwise regression model, it has been calculated that a one unit change in VO_2 @ VT could contribute to a 1.73780 second improvement in 4000m times, holding the other variables constant.

4.1.4 Maximally Accumulated Oxygen Deficit (MAOD)

The measure of maximally accumulated oxygen deficit (MAOD) has been proposed as a measure of anaerobic capacity during exhaustive exercise, it is defined as the difference between the predicted supra-maximal oxygen uptake and the actual oxygen uptake during exercise to fatigue. This method has been adapted for use during all-out exercise as an alternative procedure for the assessment of anaerobic capacity (Withers et al., 1991, Withers et al. 1993). In addition, MAOD has been established as a valid tool with which to indicate the anaerobic comparisons between athletes (Scott et al., 1991) MAOD has also been used as a tool to assess overall performance in track cyclists. According to research conducted by Medbo and Burgers (1990), results demonstrated that MAOD appears to be sensitive to differences in training status. The findings of the current study, however, do not agree with those findings. Though changes in MAOD did occur within each group, at the 0.05 level the difference between the two training protocols was not found to be significant. These findings may be attributed to short duration of the training period, though the results seem to indicate a greater increase in MAOD for the distance group; as a combined sample, the two training protocols yielded a mean increase in MAOD of 13.85%, which did prove to be statistically significant at the 0.05 level.

While MAOD is often promoted as a valuable measuring tool for anaerobic capacity and performance, it has also been suggested that MAOD is a useful tool for indicating anaerobic energy release (Medbo & Tabatta, 1989). Results of their study revealed that

MAOD increased linearly with the duration of work at the rate of 37.7 +/- 1.2 mmol/kg/s. MAOD also increased with the duration of exhaustive exercise from 30 seconds to one minute, and a further increased was revealed when the exhaustive exercise bout was extended beyond one minute. Further, for exhaustive sprint cycling exercise, Medbo & Tabatta (1993) revealed that the anaerobic processes contributed to approximately 60% of energy released. Therefore, they concluded that a high MAOD value could possibly contribute to increased anaerobic capacity and performance, which further validated earlier research that suggested MAOD as a useful measure of anaerobic capacity and performance in track cycling.

In a study conducted by Craig et al., (1993), results indicated that MAOD values for track cyclists were significantly correlated with performance in the 4000m individual pursuit. Old et al. demonstrated the practical benefits of specific anaerobic capacity training by suggesting a 10% increase in MAOD will decrease an individual 4000m pursuit time by approximately 15 seconds, further demonstrating the importance of increased anaerobic capacity in track cycling. MAOD was not found to have changed significantly for the sprint group as compared to the distance group as expected. By combining the two training methods into one sample, the changes were found to be significant at the 0.05 level, with a 13.85% increase being the mean change. Using a stepwise regression model, it has been calculated that a one unit change in MAOD would slow 4000m performance times 0.13086 seconds, holding the other variables constant.

4.1.5 Power

Westgarth-Taylor et al. (1997) investigated the effects of a modified training regimen in eight cyclists ($VO_{2\ max}$=64 ml/kg/min). A total of 15% of their endurance training was replaced by high intensity training. After six weeks, peak power (Wmax) was increased from 404+/-40W to 424+/- 53W (5.0%) and time to complete 40 km was 2.4% less. During the time trial cyclist averaged 327+/- 51W after training, compared with 291+/- 43W before (11.3%). They not only performed at a higher absolute workload but also at a higher relative intensity (8.1 vs. 72.6% Wmax), possibly indicating a shift in lactate threshold.

The same research group obtained similar results when participants trained in a similar manner for 4 weeks (Lindsay et al., 1996). Wmax was increased 4.3% and the 40 km time was improved by 3.5%.

Stepto et al. (1999) studied the effects of five different interval training protocols in 20 trained cyclists ($VO_{2\,max}$ 61.3 ml/kg/min). Cyclists completed 6 interval sessions in 3 weeks, and before and after the training period, Wmax and 40 km time trial performance were measured. The interval training protocols ranged from 12, 30 second intervals at 175% Wmax to 4, 8 minute intervals at 80% Wmax. The most profound changes in performance (2.4% increase in Wmax and 2.3% improvement in 40 km time trial performance) were observed with a protocol consisting of 8, 4-minute intervals at 85% Wmax with a 1.5min rest between each interval.

Using a group of amateur, well-trained cyclists, Bishop et al. (1998) revealed that maximal power output was a useful tool in the predication of endurance cycling performance. This finding was analogous to the results of other studies conducted on swimmers and runners (Morgan et al., 1989; Noaks et al., 1990; Scrimgeour et al., 1986; Hawley et al. 1992), which have shown that measurements of maximal power output are better predictors of athletic performance than more commonly measured physiological variables.

Noted in a training study conducted by Lindsay et al. (1996), maximal power output increased in highly trained cyclists who completed a 4-week, high intensity, interval training program. Therefore, it has been postulated that cycling performance is a combination of a cyclist's maximal power output and their ability to sustain a high percentage of that maximal power output for prolonged periods of time. Further, Lindsay et al. (1986) determined that maximal power output can account for 70-90% of the variation in cycling performance. Similarly, data from a study by Balmer et al. (2000) suggests that maximal power output can account for up to 98% in the variation of cycling performance and 21% of the variation in time trial performance.

In the current research, the sprint-trained group experienced an improvement in Max power, while the distance group actually experienced a loss in Max power. Neither of the changes experienced by either the sprint or distance group were statistically significant at the 0.05 level, nor did they show significance when combined into a single sample. Maximal power output, as measured in this particular study did give good indication as to those that

did eventually perform well, as those subjects with the highest power measures had the best 4000m times, but no correlation could be found between maximal power output and 4000m performances. Measuring power output was the most time effective and repeatable of all of the performance variables recorded within this study, which lends itself to more regular use as an indicator of training status and ability.

Average power has been shown to be the more accurate indicator of 4000m time trial performance. The nature of a 4000m time trial is such that competitors need to accelerate from a standing start up to a high speed, but instead their effort in order to complete the entire distance in a competitive time. A common experience in the sprint trained group was essentially starting too fast and ending up with very inconsistent lap times. As each group progressed through their four-week training program, their abilities to regulate their intensity improved, as did their 4000m performance. The effect of each subjects' ability to maintain a high average power output became apparent.

Once Max power had been examined, the power output data was reexamined and average power output was calculated for each group. As a combined group, the change experienced in average power output did prove to be statistically significant. Individually, the sprint group experienced a greater increase in average power output than the distance group, but neither was found to be statistically significant at the 0.05 level.

In a similar study conducted by Balmer et al. (2001), results showed that a strong relationship exists between maximal power output and 16.1 Km cycling time trial. Thus, researchers concluded that a change in maximal power output has a direct effect on cycling performance. Research has also demonstrated that maximal power output is a strong predictor of cycling time trial performance across a wide range of cycling abilities (Balmer et al., 2001). However, differences in maximal power output have been noted when comparing professional and elite cyclists.

It should also be noted that testing protocol and test duration could significantly affect the measurement of power output. Research conducted by Withers et al. (1993) demonstrated power output during four different treatment protocols, which all varied in length. Maximal power output was reached during the 5th second of the test, but this level could not be sustained for a lengthy period of time. Intraclass correlations indicated a high reproducibility in measurements for maximal power output among the four treatment

protocols. No differences were found to exist between treatments. Therefore, Wither et al. (1993) concluded that maximal power output was independent of test duration and protocol.

The testing method used in the current research, was conducted on an electronically braked cycle ergometer using a graphical computer interface (Computrainer, with coaching software). The test consisted of a 333m sprint from a standing start at maximal effort; this was identical to the first lap strategy for 4000m time trial performances. Each subject performed the test on the same bicycle and gearing used during the training and performance sessions of the program in an effort to more closely replicate actual conditions. Maximal power measures were reached within the first eight seconds of the test, just before subjects attained their max pedal cadence. The graphic representation of each subject's power curve typically indicated a spike within the first 10 seconds of the test, then a plateau, followed by a gradual decline. The subjects' ability to reduce their power decline during the 333m test illustrated their training adaptations and average power output.

In a study conducted by Craig et al. (1995), mean power output was tested in four supramaximal test durations. Results indicated a significant difference between the mean power output of each test when comparing sprint and endurance trained track cyclists with untrained individuals. Results revealed that in comparison to endurance cyclists, sprint cyclists recorded a significantly greater mean power output in the 70 second test protocol and a significantly lower mean power output in the 115% $VO_{2\ max}$ test protocol.

The training protocol used by the sprint group included many more standing start sprints within each repetition of their workouts, 92 in all over the four weeks as compared to he distance group's 44. Though these differences were designed as part of the training program, it is not felt that the distance group's lesser change in average and maximal power output is a result of unfamiliarity with the procedure.

Chapter 5. Summary and Conclusions

Subjects participating within the current research were all competitive amateur cyclists, meaning that each had at least four or more years of cycling experience, and at least one year of competitive racing experience. A group of fifteen cyclists had been guided and trained throughout a full season of competitive road cycling events by the researcher in an effort to assure a qualified subject pool from which to select participants. The eleven subjects selected were those most qualified to participate in what was to be a seven week commitment.

Although little or no data are available on the effects of training in already highly trained cyclists, (Jeukendrup & Van Diemen, 1998) anecdotal evidence suggests that improvements in performance are small, despite significant increases in training volume and intensity. The degree to which each training method and the group as a whole improved their 4000m time trial performance was in keeping with the findings of Jeukendrup & Van Diemen (1998) as well as the expectations of the researcher.

An important consideration to keep in mind with reference to the degree to which each group experienced change in their 4000m time trial performance, is that from a performance standpoint, certain variables could have been changed that may have led to greater performance differences. One component that could have had a significant influence on 4000m performance, would have been allowing the use of different gear ratios as the training program went on. The use of only one gear ratio was done in an effort to simplify the ability to track changes in performance adaptations.

Subjects within the sprint protocol began to reach a limit in their capacity to increase their pedal cadence during the duration of the 4000m time trial that was not experienced by the distance protocol. As the sprint group experienced a slightly, though not statistically significant at $P = 0.05$, higher increase in the Max Power and Average power variables. Thus it may have been possible to have taken advantage of those changes with a higher gear ratio. The use of larger gear ratios, thus allowing more bicycle speed at a given pedal cadence than a smaller gear ratio is a common practice among track cyclists. At a certain point, a given gear ratio can be too large and not benefit an individual's performance. The

next step in the process of the subjects that participated in this training program looking to further improve their 4000m performance would be to experiment with various gear ratios in an attempt to further seek performance enhancements.

The resistance a cyclist experiences as a result of air resistance is in fact the greatest external variable to overcome, followed next by rolling resistance created by the tires to the velodrome surface. The use of more aerodynamic equipment, such as solid disc wheels, aerodynamic helmets, shoe covers along with other various means of reducing aerodynamic drag as well as higher pressure tires and reducing non functional weight from both the rider and their equipment to reduce rolling resistance would allow these individuals to apply a greater percentage of their effort to generating speed rather than overcoming resistance.

In retrospect the current research can be viewed as a success from a competitive cyclist's point of view. Though traditional statistical analysis does not give the same perspective, improvements, no matter how small are what competitive athletes seek. It becomes the responsibility of the prospective 4000m individual pursuit competitor to determine whether the degree of improvement is worth the risk. As is the case with many amateur competitive cyclists, their daily lives and responsibilities may not allow them to do everything necessary in order to meet their true potential. The training portion of this program took place three days per week for two hours each day over a 4-week period.

These ten subjects that were chosen all had families and full time jobs, and were able to find the time to complete their particular training protocol without missing a session. For those cyclists that wish to improve their performance in 4000m time trials, the sprint protocol may appear be the more effective choice. Cyclists at this level of experience and participation typically have good aerobic fitness, though they train at assumed percentages of maximal effort, with out ever finding their true capacity. The sprint training protocol allowed its participants to become familiar with their true performance capacity through repeated bouts of maximal effort that became progressively longer throughout the program. Gaining familiarity with maximal capacity created a more accurate ability to judge effort and cope with the pain of very high intensity competition that did not occur through following the distance training protocol.

Too often, cycling research examines the absolute capacity with which an elite athlete can perform, often times, as compared to untrained individuals. General assumptions

must be derived from these studies in order to apply them to the average competitive cyclist. Often times these generalizations become very vague and in many magazines are taken out of context. It was the aim of this thesis project to provide insight into how the majority of the participants in the sport of road cycling could perhaps most effectively prepare themselves for a specific event in a period of time conducive to their life style. Simply put, the weekend warrior could now create a training program for improving their 4000m individual pursuit performance based on research that had the same goal in mind.

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Vita

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