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# ANAEROBIC THRESHOLD, MAXIMAL OXYGEN UPTAKE AND PERCENT BODY FAT AS PREDICTORS OF OLYMPIC DISTANCE TRIATHLON PERFORMANCE

by

GARY PALLETT

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the Faculty of Graduate Studies

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# ANAEROBIC THRESHOLD, MAXIMAL OXYGEN UPTAKE AND PERCENT BODY FAT AS PREDICTORS OF OLYMPIC DISTANCE TRIATHLON PERFORMANCE

BY

GARY PALLETT

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

MASTER OF SCIENCE

# ABSTRACT

Anaerobic threshold has been demonstrated to be the best predictor of single sport endurance performance. Maximal oxygen uptake, percent body fat and economy are other variables that have proven useful for the prediction of endurance swimming, cycling and running performance. Limited evidence indicates these variables are poor predictors of ultraendurance triathlon performance. No research to date has evaluated whether these variables are useful in the prediction of Olympic distance triathlon performance. It was hypothesized that these variables may be useful in predicting swim, cycle, run and total performance in a Olympic distance triathlon and in the development of prediction equations for the sport. Ten male subjects each completed an Olympic distance triathlon, a hydrodensitometry test, a treadmill and cycle ergometer anaerobic threshold / $VO_2$ max protocol and a three speed swim test. The results demonstrated:(a) swim velocity at anaerobic threshold was a significant predictor of swim and total performance, while $VO_2$ at anaerobic threshold during treadmill running and cycle ergometry failed to predict specific event or total performance, and (b) maximal oxygen uptake, percent body fat and economy were not good predictors of Olympic distance triathlon performance. These conclusions indicate that the factors that predict Olympic distance triathlon performance differ from those that predict single sport endurance performance. This suggests that factors that lead to decreased mechanical efficiency may be the major determinant in Olympic distance triathlon performance.

# DEDICATION

This work is dedicated to my parents, Gordon and Freda Pallett for their support in my racing and studies which made this paper possible.

# ACKNOWLEDGEMENTS

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I am indebted to James Wiebe and Julie Senecal for their help in testing the subjects in this study. Appreciation is also expressed to Edie Fisher, Ben VanDenBosch and Cheryl Pallett for proof reading sections of this work. Further, I wish to thank all of the athletes I have worked with over the years for all their effort, dedication and friendship. The times and laughs we shared made the last few years just fly by.

Last, but not least, I want to thank the participants of this study who made this work possible.

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# CHAPTER 1: INTRODUCTION

Triathlon is a continuous aerobic sport consisting of swimming, cycling and running. It began in California in 1975 when the athletes of the San Diego Track Club created a way of easing the monotony of running “workouts”. Their simple idea of swim - cycle - run caught on and today the sport is contested in over 100 nations by over a million athletes.

The initial growth of the sport in the early eighties is believed to have resulted from media coverage of the Hawaii Ironman Triathlon, an event consisting of a 3.8 km swim, 180 km cycle and a 42.2 km run. An article in Sports Illustrated and national television coverage introduced the sport to the North American public. This new public awareness resulted in a growth of races across all of North America.

Shorter distance triathlons were created in North America by endurance athletes looking for a new challenge, however it wasn’t until the development of the Bud Light United States Triathlon Series in 1984 that a standardized distance was accepted. This series consisted of races which included a 1500 meter swim, 40 km cycle and a 10 km run. These distance races are now termed Olympic distance with the acceptance of the sport into the Olympic games in Sydney Australia in the year 2000.

Early studies established that maximal oxygen uptake ($VO_2$ max) expressed relative to body weight was highest in the best athletes (Astrand & Saltin, 1961; Robinson, 1938), suggesting that it was a good predictor of athletic potential (Costill et al., 1973; Costill & Winrow, 1970; Davies & Thompson, 1979). In time it was demonstrated that although $V0_2$ max was a good predictor of athletic performance when a heterogeneous group was studied, it was a relatively poor predictor when athletes of similar ability were evaluated (Conley & Krahenbuhl, 1980; Costill & Winrow 1970; Pollock, 1977).

The best measure to ascertain mid-term and long-term endurance has subsequently proven to be the anaerobic threshold (Farrell et al., 1979; Coyle et al., 1988; Mader et al., 1976), described as the exercise intensity at which the rate of lactic acid diffusion into the blood stream is equal to its rate of removal from the blood (Mader et al., 1976). The rise in lactic acid concentration to 4 mmol/l in peripheral blood during gradual increases in workloads has been considered as one criterion for the establishment of the anaerobic threshold (Heck et al., 1985). This value of 4 mmol/l resulted from the observation that endurance-trained athletes could tolerate respective workloads for longer periods of time and that higher work loads normally resulted in a continual increase in lactate concentration (Heck et al., 1985). A third variable useful in predicting single sport (and running in particular) endurance performance is percent body fat. Numerous studies have shown a high correlation between low body fat percentages and race performance with the highest correlations existing in the sport of running (O'Toole et al., 1989).

Research into the sport of triathlon has failed to support that either maximal oxygen uptake, anaerobic threshold, percent body fat or economy are good predictors of ultraendurance race performance. In triathletes, $V0_2$ max values have been compared with overall finish time (O'Toole et al., 1988) and with finish time of a particular stage of the triathlon (Kohrt et al., 1987a), and in both cases $V0_2$ max was reported to have a moderate to poor correlation with triathlon performance. Similarly, oxygen uptake at the lactate threshold of 4 mmol/l was poorly (r = -0.37) related to bike finish time in a group of Ironman triathletes (O'Toole et al., 1988). It was therefore concluded that the optimal pace in an ultraendurance triathlon cycle of this distance could not be judged by work level at anaerobic threshold. Possible explanations for the inability of $VO_2$ max and anaerobic threshold to predict ultraendurance triathlon performance include decreases in mechanical efficiency due to fatigue and increases in core temperature, as well as other factors such as dehydration and glycogen depletion (O'Toole et al., 1989).

Unfortunately, since research has focused on ultraendurance triathlons, it is not known whether maximal oxygen uptake or anaerobic threshold can predict Olympic distance triathlon performance. Since the factors resulting in fatigue in the two distance races may be different, the ability of $VO_2$ max and anaerobic threshold to predict performance may differ as well.

## Statement of the Problem

Maximal oxygen uptake and anaerobic threshold are highly correlated to single endurance sport performance (Bompa, 1987; Costill et al., 1973; Noakes, 1988), however this relationship has failed to be demonstrated in ultraendurance triathlons (Holly et al. 1986; O'Toole et al., 1987a; O'Toole et al., 1987b). Little research has been done to see how well $V0_2$ max and anaerobic threshold can predict Olympic distance triathlon performance. Thus, the purpose of this study is to determine the extent to which anaerobic threshold, maximal oxygen uptake, economy and percent body fat contribute to the prediction of Olympic distance triathlon performance.

## Research Hypothesis

It was hypothesized that the three sport specific anaerobic thresholds (swimming, cycling and running) would be the best physiological indicators of total triathlon performance.

### Sub Hypotheses

It was also hypothesized that:

1. Anaerobic threshold as determined in lab or field tests (eg. treadmill, cycle ergometer and 3 speed swim test) would predict triathlon performance in each specific event.

2. Maximal oxygen uptake and percent body fat would also predict specific event (swimming, cycling and running) triathlon performance.

3. The longer the duration of the event the more it would correlate to total triathlon performance. Therefore, cycle time would correlate most closely with total time while swim time would correlate the least with total time of the three sports.

4. Heart rate at anaerobic threshold during each specific protocol would differ for each sport.

5. Economy measured during cycle ergometry and treadmill running would predict specific event performance in a triathlon.

## Operational Definitions

Anaerobic Threshold: the exercise intensity at which the rate of lactic acid diffusion into the bloodstream is equal to its rate of removal from the blood. This has been demonstrated to occur at 4 mmol/l of lactate in the blood.

Cumulative Fatigue: a term used to describe the additive effects preceding events have on performance.

Economy: is considered to be the steady state oxygen consumption ($ml \cdot kg^{-1} min^{-1}$) for a standardized speed.

Ironman Triathlon: a continuous aerobic event consisting of a 3800 meter swim, 180 kilometer cycle and 42.2 kilometer run.

Olympic Distance Triathlon: a continuous aerobic event consisting of a 1500 meter swim, 40 kilometer cycle and 10 kilometer run.

Percent Body Fat: relative fatness of the body as determined by hydrodensitometry.

Ultraendurance Triathlon: a continuous aerobic event consisting of swimming, cycling and running which lasts longer than four hours.

$V0_2$ max: the maximal rate at which oxygen can be used per minute; the power or capacity of the aerobic or oxygen system.

## Assumptions and Limitations

### Assumptions

It was assumed that all individuals would reach anaerobic threshold at a level of 4 mmol/l lactic acid in the blood. It was also assumed that maximal effort was exerted during the triathlon performance.

### Limitations

Due to individual differences in bone density, hydrodensiometry is only believed to be accurate within three percent body fat.

Due to time constraints maximal oxygen uptake and anaerobic threshold were measured in the same testing protocol. This may have resulted in a slightly lower $VO_2$ max because a test duration of 6 - 12 minutes is believed to be optimal for the determination of $VO_2$ max. Our test duration averaged slightly greater than 20 minutes.

Since the testing protocol was designed to determine both $VO_2$ max and anaerobic threshold, stage duration was limited to three minutes. This duration may not have been long enough for a true steady state in anaerobic threshold or economy to be achieved.

Due to the difficulty of measuring physiological variables during swimming, and equipment limitations, it was not possible to obtain a swimming $VO_2$ max during the anaerobic threshold protocol.

Results from one race may not have accurately demonstrated an athletes true triathlon ability. Factors such as quality of one's wetsuit and bicycle also effected results.

Tests were designed to determine anaerobic threshold and maximal oxygen uptake and may not have accurately given a true measure of economy.

## Significance

Previous research has demonstrated that anaerobic threshold, $VO_2$ max and percent body fat are significantly related to performance in the individual sports that comprise the triathlon. These physiological variables are not related to performance in ultraendurance triathlons. Little research has examined their ability to predict Olympic distance triathlon performance.

Determination of physiological variables important in triathlon performance will allow athletes to design more effective training programs. Identification of factors which predict Olympic distance triathlon performance will also allow researchers to more accurately describe the criteria necessary for success in the sport.

# CHAPTER 2: REVIEW OF LITERATURE

Triathlon is a continuous aerobic sport consisting of swimming, cycling and running. It evolved in the mid 1970's and has since become one of the fastest growing sports in the world. Although triathlons can be of any distance, two races have become the most accepted. The first is the Ironman Triathlon which is an ultraendurance event consisting of a 3.8 km swim, 180 km cycle and a 42.2 km run. The other is the Olympic distance triathlon consisting of a 1.5 km swim, 40 km cycle and a 10 km run.

Much research has evaluated the variables important to individual endurance sport performance. Variables such as anaerobic threshold, $VO_2$ max, and percent body fat have been found to be the best predictors of performance in the single endurance sports comprising the triathlon. Economy of motion has also proven to be a good predictor of performance in some studies (Conley & Krahenbuhl, 1980) but not others (Daniels et al., 1977). A partial explanation for this finding may be that economy is difficult to measure, and unless the testing protocol is specifically designed to measure this variable a relationship may not show up even if it exists.

Most triathlon research has focused on ultraendurance races and indicates that anaerobic threshold, $VO_2$ max, and percent body fat are not good predictors of performance. Little research has evaluated the ability of these and other variables to predict Olympic distance triathlon performance. Since the factors believed to cause fatigue in the two distance triathlons may be different it is possible the ability of variables to predict performance may differ as well.

## Olympic Distance Triathlon Performance

Little research has evaluated the factors which affect performance in Olympic distance triathlons while most research has focused on ultraendurance triathlons (Kohrt et al., 1989; Kreider et al., 1988a; O'Toole et al., 1989). Performance in Ironman triathlons (3.8 km swim, 180 km cycle and 42.2 km run) is believed to be related to the ability to sustain a higher percent of maximal heart rate and to maintain a relatively consistent pace for the duration of the race. These variables are believed to be critical in ultraendurance performance due to the duration of the event which makes efficient use of fuel reserves a critical determinant of success (Roalstad, 1989). In the Ironman triathlon, Roalstad et al. (1987) found that average heart rate as a percent of maximum for the bike portion was 78% for men and 77% for women. During the run portion of the race, the men averaged 73% of max heart rate while the women averaged 74%. Percent of maximum heart rate and performance times were significantly related during the bike portion for women (r = -0.63) and during the run portion for men and women (r = -0.85, -0.83).

Anaerobic threshold, maximal oxygen uptake, efficiency and percent body fat have all been demonstrated to be helpful in predicting performance in the individual endurance sports that comprise the triathlon. Of these predictors anaerobic threshold has been demonstrated to be the most useful (Coyle et al., 1988; Londeree, 1986; Maglischo, 1982).

## Characterization of Triathletes

Since training for a triathlon involves training for three sports as compared to single sport training, physical profiles of triathletes may differ from single sport athletes (Holly et al., 1986). Triathletes tend to be older than elite swimmers, cyclists and runners (Holly et al., 1986; Kohrt et al., 1987b; O'Toole et al., 1987c) and to have a more variable age range (20 to 50 years) (Kohrt et al., 1987b; Kreider et al., 1988a; Roalstad et al., 1989). Probable reasons for this are the short existence of the sport and the fact that most triathletes turn to the sport following years of competition in a single sport. The height of triathletes resembles that of single sport athletes (Burke, 1980; Kohrt et al., 1987b; O'Toole et al., 1987c). Male triathletes tend to weigh more than cyclists (Burke, 1980) and runners (Pollock, 1977) but less than swimmers (Holly et al., 1986). Female triathletes tend to weigh more than distance runners, but less than cyclists and competitive swimmers.

Percent body fat is a good predictor of single sport endurance performance (Coyle et al., 1988; Londeree et al., 1986). Percentages of body fat for both male (7% - 12.5%) (Loftin et al., 1988; O'Toole et al., 1987b; Roalstad et al., 1989) and female (12.6% - 22.7%) (Holly et al., 1986; O'Toole et al., 1987b; Roalstad et al., 1989) triathletes resemble that of elite cyclists (Kreider, 1988b; O'Toole et al., 1987c), while elite swimmers tend to have greater percentages of body fat and elite runners have lower body fat percentages (Kreider, 1988b; O'Toole et al., 1987a; O'Toole et al., 1987c). The reason runners have less body fat than swimmers despite similar rates of energy expenditure may be due to differences in substrate utilization during running and swimming (Flynn et al., 1989; Jang et al., 1989).

Lowman (1982) has suggested a range of 4% to 10% body fat for males and 13% to 18% for females as optimal for physical performance without regard to specific sport. The value of percent body fat in predicting race performance has been demonstrated in runners where a multiple step-wise regression analysis revealed that the best predictive model of 10 km race performance was the combination of percent body fat, ventilatory threshold and $V0_2$ max which accounted for 92% of the total variance in race performance (Bednarski, 1987).

## Maximal Oxygen Uptake and Triathlon Performance

Traditionally, the cardiorespiratory variable most closely associated with performance in endurance events has been maximal oxygen uptake (Mitchell et al., 1958; Mitchell & Bloomquist, 1960). Previous research has demonstrated a strong inverse relationship ($r = -0.90$ and $r = -0.87$) of $V0_2$ max to race performance in distance runners (Costill et al., 1973; Daniels et al., 1977; Davies & Thompson 1979) and (-0.47 and -0.87) and in competitive cyclists (Coyle et al., 1988; Krebs et al., 1966; Malhotra et al., 1984). The relationship between $V0_2$ max and triathlon performance is not as strong as in the individual sports that comprise the event. Low to moderate correlations have been demonstrated between $VO_2$ max and triathlon performance (O'Toole et al., 1987a). Cumulative fatigue from a preceding section may diminish $VO_2$ max ability to predict performance (O'Toole et al., 1989).

A number of studies have shown that the oxygen uptake achieved during maximal work is dependent upon the mode of exercise and the specific training of the athlete (Albrecht et al., 1986; Delistraty & Noble, 1987; Dengel et al., 1989). It has further been demonstrated that maximal oxygen uptake is related to active muscle mass (Albrecht et al., 1986; Kohrt et al., 1989). Thus, most individuals obtain higher $V0_2$ max results running than cycling or swimming due to an increase in active muscle mass during activity. Maximal oxygen uptake in

$ml \cdot kg^{-1} \cdot min^{-1}$ is also very dependent on body fat percentages, as it has been demonstrated for every percent increase in fat, the $V0_2$ max is reduced by slightly more than a percent.

$V0_2$ max values in male triathletes range from 49.7 to 75.4 $ml \cdot kg^{-1} \cdot min^{-1}$ during treadmill running to 43.6 to 70.3 $ml \cdot kg^{-1} \cdot min^{-1}$ during cycle ergometry (Krebs et al., 1966; Kreider, 1988b; O'Toole et al., 1987c). Since triathletes train less in any one sport than single sport athletes, the achievement of $V0_2$ max values that are comparable to those of elite single sport athletes may demonstrate a true cross-training effect (O'Toole et al., 1989). Results from investigations of the relationship of $V0_2$ max to race performance have been variable. Otto et al., (1985) evaluated the relationship between aerobic capacity and performance in a shorter distance triathlon (1600 meter swim, 45 km cycle, 10 km run) and found that maximal aerobic power measured by arm and cycle ergometry was not significantly related to performance times in either the swim or cycling portions of the triathlon, although run time was significantly related to treadmill $V0_2$ max. Other investigations (Kohrt et al., 1987a; Kohrt et al., 1987b; O'Toole et al., 1988) have reported significant relationships between performance time in cycling and peak $V0_2$ during cycle ergometry ($r = -0.68, -0.78, -0.83$), in both Ironman distance (180 km) and two half Ironman distance races (90 km.) respectively. Performance times in the run portion of a triathlon have also been significantly related (r

= -0.68 and -0.73) to peak $V0_2$ (Kohrt et al., 1987a; O'Toole et al., 1988).

In a study comparing peak $V0_2$ during tethered swimming to swim times (Holly et al., 1986), the correlation did not reach statistical significance (r = -0.50). Perhaps the lack of significant correlations to swim times is partially due to the significant lower peak $V0_2$ measured by tethered swimming (46.8 ml $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$) as compared to treadmill (57.4 ml $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$) or cycle ergometry (54.4 ml $\cdot$ $kg^{-1}$ $\cdot$ $min^{-1}$), or to the fact that other factors such as efficiency may have a greater effect on swimming performance (Kohrt et al., 1989). However, these results are disputed by Kohrt et al. (1987a) who discovered a correlation of r= -0.87 between swimming $V0_2$ max and 1.9 km lake swim performance. Loftin et al. (1988) discovered low to moderate but not significant, relationships between $V0_2$ max during cycling and running and 40.3 km cycle and 10.0 km run performance in recreational triathletes. Dengal et al. (1989) also failed to find that $V0_2$ max was a good predictor of race performance, finding correlations of r = -0.49, -0.32 and -0.55 to swim, cycle and run times.

In ultraendurance triathletes, O'Toole et al. (1987c) reported that treadmill and cycle ergometer $V0_2$ max had correlations of r= -0.58 and -0.52, respectively to Hawaii Ironman triathlon performance. In another study, she found no significant relationship between Ironman finish times and $V0_2$ max values during treadmill running (r = -0.09), cycle ergometry (r = -0.04), or arm ergometry (r = -0.19) (O'Toole et al., 1987b) .

The ultraendurance triathlon, however, is a different type of endurance event, requiring the athlete to produce large amounts of energy aerobically in three different sports performed consecutively for prolonged periods of time. Thus, the relationship of $V0_2$ max to performance may not be as definitive as is often seen in single sports (O'Toole et al., 1987b).

## Anaerobic Threshold and Triathlon Performance

In running, swimming and cycling, success has been directly related to the ability to use a large percentage of maximal aerobic power with minimal accumulation of lactic acid (Costill et al., 1973; Coyle et al., 1988; Maglischo et al., 1982). The rise in lactic acid concentration to 4 mmol/l in peripheral blood during gradual increases in workloads can be considered as the criteria for the establishment of the anaerobic threshold (Jacobs, 1986). This 4 mmol/l threshold has been shown to be closely related to single sport endurance performance (Heck et al., 1985; Mader et al., 1976; Madsen, 1982).

Most triathlon research (Kreider et al., 1988a; Mayers et al., 1986; O'Toole et al., 1988) however, not all (Kohrt et al., 1987a) has shown anaerobic threshold to be a poor predictor of ultraendurance triathlon performance. No previous research has evaluated the ability of anaerobic threshold to predict Olympic distance performance.

The only study to date supporting anaerobic threshold being a good predictor of performance was conducted by Kohrt et al. (1987a) on triathletes who had completed a half Ironman triathlon. Correlations of r= -0.72 and -0.82 were found between the 4 mmol/l threshold and cycle and run performance times, respectively. These findings conflict with O'Toole et al. (1988) who found correlations of r = -0.37 and -0.26 between $VO_2$ at 2.0 and 4.0 mmol/l lactate thresholds and cycle times during the Hawaii Ironman triathlon. These findings suggest that other factors such as the environment or race duration may influence the ability of anaerobic threshold to predict performance. To date no study has evaluated anaerobic threshold in triathlete swim performance.

Laboratory simulated triathlons have not found anaerobic threshold to be a good predictor of performance (Kreider et al., 1988a; Mayers et al., 1986). These simulated triathlon findings suggest cumulative fatigue and increases in core temperature result in thermoregulatory and cardiovascular adaptations that act to decrease anaerobic thresholds ability to predict performance (Kreider et al., 1988a; Mayers et al., 1986).

# Blood Lactate as a Limiting Factor in Exercise Performance

## Lactate Levels at Rest

At rest lactate is present in the blood and muscle, usually in the range of one to two millimoles per liter. The source of this lactate is probably due to the low resting metabolic rate of muscle that occurs with a low blood flow and the fact that erythrocytes also have a low and constant metabolism, the metabolic end product of which is lactate (Gollnick et al., 1986). At exercise intensities below 40% of $V0_2$ max in untrained individuals, and 70% of $V0_2$ max in highly trained endurance athletes, there may be little or no change in the lactate content in the muscle or blood. With increasing intensities of exercise beyond these percentages, the rise in lactate concentration of blood and muscle becomes exponential (Gollnick et al., 1986; Wasserman et al., 1967). The intensity of exercise that elicits this rise in lactate concentration in muscle and blood is highly variable. Both cross sectional and longitudinal studies have demonstrated that endurance training results in decreased muscle and blood lactate accumulation at given absolute or relative exercise intensities (Mader et al., 1976).

## Accumulation of Blood Lactate

With some, but not all, intensities of exercise, lactate accumulates in the blood and the muscles engaged in the exercise (Gollnick et al., 1986). The blood lactate level is dependent on it's rate of production (Ra) and it's rate of removal (Rd). At rest, a steady state is achieved (Ra = Rd), however, during intense exercise production exceeds removal (Ra > Rd) and lactate levels increase. The reason for the increased accumulation may be due to an increase in production, a decrease in removal or both (Brooks, 1985).

The role of lactate production is to release some of the energy contained in the glucose molecule and to transfer it to ADP for the production of ATP. The simplest explanation for this process is that lactate production is the emergency (anaerobic) method for ATP production or, in the case in which the oxygen uptake of the body is high or near maximal , a supplement to the normal production of ATP. The net production of ATP from the degradation of glucosyl units to lactate releases only about 10% of the total energy stored in the glucose molecule. Though small, under some circumstances this ATP provides the difference between mediocre and high level performance (Gollnick et al. 1986). Once released most (75% +) of the lactate formed during sustained, steady-rate exercise is removed by oxidation during exercise, and only a minor fraction (20%) is converted to glucose (Brooks, 1985).

The basic determinants of lactic acid removal from the blood by active muscle appear to be the concentration of lactate in the blood and the activity level. The higher the blood lactate concentration and activity level, the greater the net removal of lactate from the blood. The removal of lactic acid from the blood is also significantly affected by effectors of glycolysis, glycogenolysis, and gluconeogenisis (Gollnick et al.,1986).

During progressive exercise the addition of lactic acid to the blood from active muscle rises in increasing proportion to the increasing number of muscle fibers activated and the intensity of activation. In the early stages of the test, lactate removal from the blood increases with the gradual acceleration in production. As a result, the rate of rise of blood lactate will be slow during the initial stages of the test. However, when blood epinephrine begins to rise during the progress of the test, the contribution of lactic acid by the active muscles will be increased while the removal by other tissues will be decreased or switched to addition to the blood. Thus the blood lactate concentration would be expected to rise in a curvilinear manner as work and $V0_2$ increase. The blood lactate rises slowly at the lower work rates and then rises progressively more rapidly as work rate and $V0_2$ rise to $V0_2$ max (Stainsby & Brooks, 1990).

At rest and/or during submaximal exercise, lactate concentration can be elevated in the heat (Fink et al.,1975), in the cold (Jacobs et al., 1985), and may be reduced when the subject is dehydrated (Saltin, 1964). Neither heat nor thermal dehydration seem to affect peak blood lactate concentrations after supramaximal exercise (Jacobs, 1986). Fiber type is another variable affecting lactate concentration. Fast twitch fibers produce double the lactate slow twitch fibers produce (Jacobs, 1986).

Depletion of muscle glycogen stores either by dietary or exercise manipulations reduces intramuscular lactate accumulation after short term, high intensity exercise (Jacobs, 1986). Blood concentrations at specific absolute and relative exercise intensities are also reduced after both submaximal and supramaximal exercise with severely depleted glycogen stores (Foster et al., 1988; Jacobs, 1986; Jansson, 1980).

## Effects of Endurance Training on Blood Lactate Concentrations During Exercise

Endurance training and/ or detraining studies typically employ changes in the capacity of endurance exercise (Jacobs, 1986). However, it is being increasingly suggested that parameters being measured during submaximal exercise may be more valid indicators of training status than $VO_2$ max (Heck et al., 1985; Mader et al., 1976). The lactate response to a given exercise is such an indicator and is being increasingly used as a longitudinal marker of the adaptation to endurance training (Jacobs, 1986).

A myriad of studies have demonstrated via both cross sectional and longitudinal comparisons that endurance training results in decreased muscle and blood lactate accumulation at given or relative exercise intensities (Coyle et al.,1988; Heck et al.,1985; Farrell et al., 1979). Therefore, the curve generated by plotting concentration of lactate in blood against the absolute and relative intensities shifts to the right following endurance training (Hermansen, 1972). These findings have been supported by Saltin et al., (1976) who did studies on athletes with one trained leg and then performed two-legged exercise. In these studies there was a net uptake of lactate by the muscles that were endurance trained compared to a release from the nontrained muscles.

Also associated with the metabolic response to training is a lower rate of glycogen consumption and a greater use of fat as a source of energy. This is illustrated by the respiratory exchange ratio, the respiratory quotient across the contracting muscles, and the lower rate of glycogen depletion of the exercising muscles (Gollnick et al., 1986) This enhanced fat use and glycogen sparing following endurance training exists both for the whole body and for individual legs when the subjects train only one leg (Hermansen, 1972; Saltin et al., 1976).

Endurance training produces some effects on the hormonal response to exercise which could be important to the altered lactate response to submaximal exercise. For example, there are smaller increases in concentrations of epinephrine and nor epinephrine at the same absolute and relative work loads after, as compared to before, endurance training (Gollnick et al.,1986). The strong adrenergic response to exercise may be responsible for the higher lactate concentrations in muscle and blood in the untrained state. This could occur, since these hormones are known to have an additive effect on the activation of glycogenolysis. This may produce an activation of glycogenolysis that is in excess of the true metabolic need. The excess pyruvate would be reduced to lactate via a mass action effect of the lactate dehydrogenase system (Gollnick et al., 1986).

With endurance training there is also an increased concentration of mitochondria (mitochondrial protein) in muscle which may influence the manner in which ADP is handled within the cell. With more mitochondria, there is a greater chance for the transport of ADP into the mitochondria to stimulate oxidative metabolism. The net result is to maintain a higher ATP/ADP ratio which will suppress glycogenolysis. Also, there will be more mitochondrial transport sites as mitochondrial concentrations increase, thus decreasing pyruvate accumulation in the cytosol and not allowing lactate formation via mass action of lactate dehydrogenase (Gollnick et al.,1986).

## Desired Lactate Levels in the Blood During Training

One of the fine arts of coaching lies in the ability to design training sessions that provide the level of stress needed for optimal physiological improvements without exceeding the athletes tolerance (Costill, 1972). Training at an exercise intensity corresponding to a certain blood lactate concentration may provide an optimal stimulus to induce the physiological adaptations associated with training (Jacobs, 1983).

Maintaining a speed at which muscle lactate production just exceeds removal is optimal for aerobic improvements, as physiological mechanisms involved in aerobic metabolism are believed to be maximally overloaded at that point (Mader et al., 1976). Mader and his associates have indicated that for most athletes, the critical training speed corresponds to a blood lactate concentration of 4 mmol/l . Swimming speeds that produce a blood lactate concentration of 4 mmol/l are considered optimal for aerobic training. This threshold level is also important during long endurance running races, as runners appear to set a race pace which allows the utilization of the largest possible $V0_2$ which just avoids the exponential rise in plasma lactate (Farrell et al., 1979).

World class endurance athletes may reach anaerobic threshold at 85% to 90% of their $V0_2$ max, while athletes of less ability will achieve anaerobic threshold at a lower percentage of $V0_2$ max. These differences in anaerobic threshold as percent of $V0_2$ max may be accounted for by differences in training or by differences in hereditary factors such as the proportion of fast and slow twitch muscle fibers (Jacobs, 1986). Because slow twitch fibers have a greater capacity for aerobic metabolism than fast twitch fibers, athletes with a greater percentage of slow twitch fibers should produce less lactate at a given workload. Other factors which influence lactate accumulation include capillary density, respiratory capacity and the activities of key oxidative and glycolytic enzymes. The strong relationship between endurance performance and lactate related variables can probably be attributed to both central circulatory enhancement and peripheral changes (Jacobs, 1986).

The use of the blood lactate "profile" has achieved considerable popularity as a non-intrusive, sport-specific method for evaluating responses to training in competitive athletes (Foster et al., 1988). The ease of testing has made this procedure particularly common in swimming. More recently, athletes in other endurance sports have realized the benefits of this type of testing for determining the capacity of the aerobic system (Bompa, 1987; Farrell et al., 1979; Troup, 1986).

The blood lactate profile is usually interpreted with two assumptions. The first is that a right shift in the power output, lactate or velocity, lactate relationships is indicative of improved conditioning status, while secondly, linearity is assumed (Mader et al.,1976). The shift of the lactate profile to the right indicates an improvement in the sport specific aerobic capacity and the ability of an athlete to be able to compete faster at 4 mmol/l. A downward shift also indicates an increased specific aerobic capacity, or a lower lactate value for the same velocity. A shift to the left, or an upward shift, indicates a deterioration of the sport specific aerobic capacity (Mader et al., 1976). Research has suggested that not only endurance training, but other factors such as fatigue and overtraining affect lactate production and may result in an artificial shift right (Fric et al., 1988). Therefore, the importance of standardization must be stressed before the interpretation of any results can be made.

The real advantage of these tests may be the ability to plan and monitor a season's training by making comparisons based on a previous season's data. Thus, the coach can evaluate the profiles at each stage in the season and provide information on the progress of training. Variations in the appearance and movement of the curves should be expected for each athlete, as individual lactate profiles are very different (Prins, 1988).

## Specificity of Training

Elite athletes who train only in cycling or running generally achieve a higher $V0_2$ max on the work modality which is specific to their training. In other words, competitive cyclists may achieve a higher $V0_2$ max on the cycle ergometer than the treadmill (Hagberg, 1984; Withers et al., 1981), whereas trained runners typically have a higher $V0_2$ max on the treadmill compared to the cycle ergometer (Withers et al., 1981). Furthermore, trained cyclists have been reported to attain a significantly higher anaerobic threshold than runners on the cycle ergometer, whereas runners achieve a higher anaerobic threshold than cyclists on the treadmill (Withers et al., 1981). These investigations of athletes who train in only one sport suggest that adaptive responses to chronic endurance exercise are in part a function of specific movement patterns executed in training (Schneider et al., 1990).

Kohrt et al. (1987a) found that triathletes did not obtain as high a percentage of treadmill $V0_2$ max on a cycle ergometer or when swimming, as did cyclists or speed swimmers. However, triathletes obtained higher percentages than untrained individuals. The study concluded mean $V0_2$ max during cycling was 95.7% of the treadmill value, which is greater than the value typically found in non-cyclists (88% to 92%) but less than that of highly trained cyclists (98% to 105%). Mean $V0_2$ max during tethered swimming was 86.6% of the treadmill value. As in cyclists, this percentage is greater than that of recreational swimmers (78% to 82%) but less than that of elite swimmers (93% to 95%).

Another study determined the lactate threshold ($V0_2$ at a lactate concentration of 4 mmol/l) at peak training, and following 3 months of decreased cycle and swim training, while the training volume for running was held constant (Kohrt et al., 1987b). The lactate threshold for cycling decreased significantly during cycling detraining, whereas the lactate threshold for running did not significantly decrease, suggesting that training adaptations are specific to the muscles involved in training (Kohrt et al., 1987b). Kohrt et al. (1989) also measured the lactate threshold for cycling and running four times over a seven month period to monitor adaptations to multiple modes of training. The amount of improvement in $V0_2$ at lactate threshold was greatest in the event with the highest training volume, which also supports the theory of training specificity as it relates to the anaerobic threshold in triathletes.

## Thermoregulation and Cardiovascular Adaptations and their Importance to Triathlon Performance

Thermoregulatory requirements may explain the differing physiologic response to single endurance sport and triathlon performance (Davies & Thompson, 1986). During prolonged performance such as triathlon there is a gradual increase in core temperature resulting in a shunting of blood to the cutaneous vessels to dissipate heat (Boone & Kreider, 1986). The vasodilation of peripheral vessels reduces mean arterial pressure resulting in a decreased ventricular filling pressure and stroke volume (Brengelmann et al., 1977; Rowell, 1974; Sawka et al., 1979). In order to maintain cardiac output, heart rate gradually increases. Oxygen uptake at a given work output also increases as mechanical efficiency diminishes during prolonged exercise (Davies & Thompson, 1986; Sawka et al., 1984). The elevated oxygen requirement is accommodated through a gradual elevation in peripheral extraction in the active muscle (Rowell, 1974; Sawka et al., 1979; Sawka et al., 1984).

Kreider et al. (1988a) found core temperature increased by 2.7 degrees celsius in a simulated triathlon, ( 0.8 km swim, 40 km cycle, 10 km run ) while it increased only 1.7 and 1.8 degrees celsius, respectively, in isolated cycle (40 km) and run (10 km) protocols. The major difference between the control and triathlon sessions appeared to be the cumulative effects of the triathlon events, most evident during the run portion. The athletes began the triathlon run with a post cycling core temperature of 38.4 degrees celsius versus an initial control run core temperature of 37 degrees celsius. This elevated core temperature is believed to have caused an average drop in mean arterial pressure of 13 mmHg and a decrease in stroke volume of 9 ml·min-1 during the triathlon run in comparison to the control run. Consequently, heart rate was a mean 13 beats per minute higher than control values in order to maintain cardiac output. A decrease in mechanical efficiency apparently increased the mean oxygen uptake (+ 0.44 l.min $^{-1}$) and ventilation (+ 12.9 l. min $^{-1}$) required to perform the triathlon run. The elevated oxygen uptake was accommodated by a 1.9 ml·100 ml $^{-1}$ mean increase in peripheral extraction of oxygen (Kreider et al., 1988a).

## Mechanical Efficiency and Triathlon Performance

Considerable disagreement exists as to the importance of mechanical efficiency to performance in individual endurance sports (Costill et al., 1973; Daniels, 1985; Farrell et al., 1979). Part of the disagreement arises because efficiency is difficult to define and even more difficult to accurately measure. Terms such as “requirement”, “cost”, “oxygen cost” and “energy cost” have all found their way into the description of efficiency and refer to very different parameters (Daniels, 1985).

Efficiency refers to the relationship between work done and energy expended. The terms efficient and efficiency should not be used to relate energy demands to velocity of movement because velocity represents only part of the work being performed by the body while it is transported from one point to another. For this reason “economy” is more applicable to the description of the relationship between velocity and energy expenditure (Daniels, 1985).

Economy varies considerably among trained athletes (Conley & Krahenbuhl, 1980; Daniels et al., 1977; Farrell et al., 1979). Correlations between running economy and performance in running events has ranged from $r = 0.36$ to 0.60 (Daniels et al., 1977; Farrell et al., 1979) in athletes who are heterogeneous in ability. Conley and Krahenbuhl (1980) concluded that among highly trained and experienced runners of comparable ability and similar $VO_2$ max, running economy accounts for a large and significant amount of the variation observed in performance.

There is a paucity of knowledge regarding the relationship of economies of motion and performance times in triathletes. Kreider et al. (1988a), suggested that maintenance of efficiency is ultimately the determinant of success during triathlons. He argued that triathlon performance elicited cardiovascular and thermal adjustments not experienced when performing the events independently and that these adaptations, combined with a decrease in mechanical efficiency, limited performance during prolonged triathlon performance.

Dehydration is another factor believed to decrease economy and efficiency (Sawka et al., 1984). In one study diuretic induced dehydrated subjects demonstrated a 2.62 minute increase in 10,000 meter running performance when mean plasma volume was reduced 9.9% compared to when they were normally hydrated (Armstrong et al., 1985). Fink (1982) demonstrated that losing 2% to 3% of the body's fluid through dehydration ( almost 3 or 4 pounds of body weight ) will decrease performance by 3% to 7% in runners competing in 10,000 meter races. Kreider et al. (1988a) reported a 3% loss of body weight in his simulated triathlon study.

## Heart Rate and Triathlon Performance

Heart rate at anaerobic threshold has been demonstrated to be sport specific (O'Toole et al., 1989; Kohrt et al., 1989). Therefore, the development of sport specific protocols are essential for the determination of optimal training intensities. Some of the factors that lead to cumulative fatigue are believed to effect heart rate and diminish it's ability to predict performance.

During a triathlon in the heat a water loss of 3% may occur after only one or two hours. For a 70 kilogram athlete this means a fluid loss of 2.1 kilograms. This fluid loss causes a decrease of circulating blood volume, resulting in less blood return to the heart. This diminished blood volume is compensated by an increase in heart rate (Janssen, 1987).

Elevation in core temperature also effects heart rate during exercise. A rise in body temperature from 37 degrees celsius to 38 degrees celsius has been demonstrated to result in a 10 to 15 beats per minute increase in heart rate (Janssen, 1987). In high external temperatures and air humidity the body is more heavily taxed during physical exercise. With an equal level of exertion these factors cause a rise in pulse rate. As external temperature and humidity rise the performance reserve for endurance loads diminishes (Janssen, 1987).

Through regular training at high temperatures the body adapts itself causing a less rapid loss of capacity. Well designed clothing which does not limit heat loss and an adequate water intake before and during training contribute to maintaining a high performance level. When external temperature increases strongly, overnight pulse rate at rest or during exercise will always be higher. This goes together with a decreased performance capacity. After some days of acclimatizing with training adapted to it, the old level will soon be reached again (Janssen, 1987).

Runners will have more problems than cyclists in hot weather. Since speed and air cooling is greater in cycling than in running, greater fluid losses and elevations in core temperature will occur during running. This will result in a more elevated heart rate while running than cycling in the same environmental conditions.

# CHAPTER 3: METHODS AND PROCEDURES

## Subject Recruitment and Selection

The study consisted of 10 male triathletes aged 21 to 36 years of age. To be eligible for the study a subject must have completed the 1990 Pinawa Olympic distance triathlon in 2 hours and 20 minutes or less and must have been between 18 and 39 years of age (male open category).

The results from this race were evaluated and all individuals who met the criteria were invited to participate in the study.

## Experimental Design

A correlational quasi experimental approach was used to attempt to answer the problem. This design consisted of one test group who performed all of the tests. These tests included maximal oxygen uptake and anaerobic threshold protocols on the cycle ergometer and treadmill, an anaerobic threshold protocol while swimming, and a hydrodensiometry test for the determination of percent body fat. These physiological variables were then correlated to swim, cycle, run and total time performance variables in the 1991 Pinawa Olympic distance triathlon.

## Procedures

### $V0_2$ max Protocols

The following protocols were designed to allow the accurate determination of $V0_2$ max and anaerobic threshold during one test (Kohrt et al., 1987a).

1) Treadmill protocol

Subjects underwent incremental tests to volitional exhaustion on a motor driven treadmill. Speed was increased every 3 minutes by 26.8 m min from 161 m min to 214 m min, after which grade was incremented by 2.5%. Results were then inspected for a plateau in $V0_2$. If the last increase in $V0_2$ associated with an increase in power output was greater than 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ subjects performed a "supermaximal" test after resting 10 minutes. This test consisted of a 2 minute warm-up at a sub maximal load, followed immediately by 2 minutes at a power output greater than that at which they have previously stopped. This was repeated until a plateau in $V0_2$ was attained.

### 2) Cycle ergometer protocol

Tests were performed on a manual load Monark cycle ergometer (Ergomedic 818 E) equipped with toe clips and a racing saddle. An electronic metronome paced subjects at 80 rpm. The initial resistance of 1.5 kg. was increased by 0.33 kg. every 3 min until volitional exhaustion. If the last increase in $VO_2$ was greater than 150 ml min subjects would perform a supermaximal load as described in the treadmill protocol.

## Metabolic Measurements

Oxygen consumption was calculated using a Metabolic Measurement Cart (MMC) (Sensormedics) and a Daniel's non-rebreathing valve. Heart rate data was recorded at the end of each stage using a sport tester model PE 3000 (Polar, U.S.A.). Pre and post test calibrations were performed on the MMC to ensure gas mixtures were properly calibrated during each test.

## Determinization of Anaerobic Threshold

Anaerobic threshold was defined as the $V0_2$ corresponding to a lactate concentration of 4 mmol/l and was determined by measuring blood lactate concentration after each stage of the incremental running and cycling $V0_2$ max tests. The $V0_2$ at 4 mmol/l lactate concentration was calculated by linear interpolation.

## Three Speed Swim Test

This test was a modification of the "Zwei-Strecken" or "Two-point" test developed by Mader et al. (1976). It consisted of three consecutive 400 meter swims, each one performed in a faster time. The first 400 was swum at a time corresponding to 80% of the velocity of the best time for this distance, the second at 90% and the third at maximal effort.

The use of three efforts at ascending intensities provided a way to estimate the lactate inflection point. Since the lactate profile is linear and then goes exponential the three speed protocol decreased the error involved in linear interpolation. A manual 15 second count was used for determination of heart rate immediately following each swim.

## Determination of Blood Lactate

Anaerobic threshold was defined as the $VO_2$ corresponding to a blood lactate concentration of 4 mmol/l and was determined by measuring blood lactate concentration after each stage of the incremental running and cycling $VO_2$ max tests. At the end of a stage, subjects stopped exercising for 15 - 30 seconds while a fingertip puncture was performed and 20 microlitres (ul) of blood was obtained. During the swim tests blood lactate samples were taken three minutes following each swim and 20 microlitres (ul) of blood were obtained. Lactate concentration was determined with a lactate analyzer (YSI model 27). This analyzer was calibrated prior to sampling using YSI standard 5.0 mmol lactate, with linearity being checked with a 15.0 mmol standard.

## Economy

Economy was defined as the oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) for a given standardized submaximal velocity. Economy was measured in both the cycle ergometer and treadmill protocols. During both protocols $VO_2$ was measured in the final thirty seconds of the fifth stage for the determination of economy. The fifth stage was chosen because in most individuals this stage was close to anaerobic threshold.

## Body Composition and Anthropometric Measurements

Body density and percent body fat were determined by hydrostatic weighing using the formula of Brozek et al. (1963). Residual volume was measured outside the weighing tank using the nitrogen-dilution method described by Wilmore (1969).

Weight was taken using an electronic scale, DIGI model DS-410 which was accurate to the nearest .05 of a kilogram.

Height was established using a wall ruler and having the subject stand with their back to the wall while being measured.

## Olympic Distance Triathlon

All subjects completed the 1991 Pinawa Olympic distance triathlon (1500 meter swim, 40 km. cycle, 10 km. run) in which swim, cycle, run and total times were recorded.

## Instrumentation

Lactate Analyzer (YSI model 27)
Metabolic Measurement Cart (MMC) (Sensormedics)
Sport Tester Model PE 3000 (Polar U.S.A.)

Densitometry Tank
Electronic Scale (Digi. Model DS-410)
Monark Ergometer (Ergomedic 818 E)

## Statistical Analysis

Simple regression was used to determine the relationship between physiological test results and performance. Performance times were entered as dependent variables and were compared to the independent variables which were the predictors of performance. Relationships were considered significant if they met a minimal ($p \leq 0.05$) level of significance.

The dependent variables were taken from the results of the 1991 Pinawa triathlon. They consisted of the swim, cycle, run and total performance time. The hydrodensitometry test determined the independent variable percent body fat. The three speed swim protocol included best 400 meter swim time, swim velocity at anaerobic threshold, anaerobic threshold heart rate while swimming, maximal heart rate while swimming and maximal lactate while swimming.

Cycle ergometer and treadmill anaerobic threshold / $VO_2$ max protocols measured sport specific $VO_2$ at anaerobic threshold, maximal oxygen uptake, heart rate at anaerobic threshold, maximal heart rate, time to exhaustion and economy which were all independent variables. The final independent variable was the number of years experience the athlete had competing in triathlons.

After the simple regression was completed the eight best predictors for each dependent variable were entered into a multiple regression formula to develop prediction equations for each dependent variable. For the development of the prediction equations only the independent variables derived from the four physiological tests were entered into the equation.

In each of the four prediction equations the assumptions of regression were tested (Appendix G). These assumptions include 1) linearity; 2) homoscedasticity and 3) extreme residuals. All four equations were able to meet all of these assumptions.

A paired t-test was done to compare $VO_2$ variables from the cycle and run protocols. A one factor ANOVA test for repeated measures was conducted to determine if any differences existed between heart rate variables obtained from all three sport specific anaerobic threshold protocols. Significance was demonstrated using a Scheffe F-test with a minimal significance level of $p \leq 0.05$.

# CHAPTER 4: RESULTS

## Subject Characteristics

The descriptive characteristics of the subjects are presented in Table 4-1. All of the subjects were males currently amongst the top provincial athletes in Manitoba. Four of the ten athletes were on the Manitoba provincial team. The majority of athletes had an initial sport background in running.

## Olympic Distance Performance

Table 4-2 summarizes the subject's performance times for the July 27th, 1991 Pinawa Triathlon. The average total time from this group of subjects was 2:10:40 (2:00:26 - 2:20:31). This total performance time is comprised of the three individual events, a 1500 meter swim, a 40 kilometer cycle and a 10 kilometer run. The importance of these three performance times in predicting total performance is demonstrated in Table 4-3. Cycling ($p \leq 0.01$) and swimming ($p \leq 0.05$) performance were both significantly correlated to total performance while running was not. The environmental conditions for the race were far from ideal with a peak temperature of 28 degrees celsius and a 10 km per hour south wind. Water temperature was a cold 18 degrees celsius forcing the use of wetsuits.

**TABLE 4-1. Physical characteristics and sport experience of 10 male triathletes.**

| Subject No. | Age (yrs) | Weight (kg) | Height (cm) | Body Fat (%) | Years In Tri's | Previous Sport |
|---|---|---|---|---|---|---|
| 1 | 28.4 | 77.2 | 186.0 | 10.9 | 5.0 | cyclist |
| 2 | 33.8 | 62.0 | 161.0 | 10.5 | 7.0 | runner |
| 3 | 34.6 | 68.7 | 175.0 | 7.1 | 6.0 | swimmer |
| 4 | 36.0 | 74.1 | 184.0 | 9.0 | 5.0 | runner |
| 5 | 21.4 | 86.0 | 189.0 | 8.6 | 3.0 | swimmer |
| 6 | 20.6 | 74.8 | 181.0 | 5.5 | 3.0 | runner |
| 7 | 21.2 | 67.1 | 167.0 | 9.2 | 3.0 | swimmer |
| 8 | 21.4 | 75.9 | 182.0 | 9.0 | 2.0 | runner |
| 9 | 27.6 | 82.5 | 173.0 | 11.6 | 1.0 | runner |
| 10 | 33.5 | 79.8 | 181.0 | 12.4 | 3.0 | runner |
| Mean | 27.4 | 74.8 | 177.9 | 9.4 | 3.8 | |
| ±S.D. | 6.3 | 7.3 | 8.8 | 2.1 | 2.1 | |

Table 4-2. Performance times (hr : min : sec) and rank order of 10 male triathletes completing an Olympic distance triathlon.

| Subject No. | Swim Time 1500 meters | Cycle Time 40 kilometers | Run Time 10 kilometers | Total Time |
|---|---|---|---|---|
| 1 | 21:09 ( 6)* | 1:00:14 ( 1) | 39:03 ( 1) | 2:00:26 ( 1) |
| 2 | 19:03 ( 3) | 1:04:19 ( 3) | 39:32 ( 2) | 2:02:54 ( 2) |
| 3 | 18:32 ( 1) | 1:06:18 ( 5) | 40:47 ( 4) | 2:05:37 ( 3) |
| 4 | 21:05 ( 4) | 1:03:43 ( 2) | 41:42 ( 5) | 2:06:30 ( 4) |
| 5 | 18:37 ( 2) | 1:06:51 ( 6) | 44:53 (10) | 2:10:21 ( 5) |
| 6 | 21:42 ( 7) | 1:05:45 ( 4) | 43:13 ( 6) | 2:10:40 ( 6) |
| 7 | 21:06 ( 5) | 1:08:49 ( 8) | 44:01 ( 8.5) | 2:13:56 ( 7) |
| 8 | 25:00 ( 9) | 1:08:06 ( 7) | 43:41 ( 7) | 2:16:47 ( 8) |
| 9 | 28:49 (10) | 1:10:21 ( 9) | 39:44 ( 3) | 2:18:54 ( 9) |
| 10 | 24:17 ( 8) | 1:12:13 (10) | 44:01 ( 8.5) | 2:20:31 (10) |
| Mean | 21:56 | 1:06:40 | 42:04 | 2:10:40 |

* ( ) indicates rank order

## Anaerobic Threshold

A one factor ANOVA test of repeated measures demonstrated significant differences between heart rate at anaerobic threshold (AT-HR) during swimming, cycling and running (Table 4-4). Paired t-tests, however failed to show a significant difference between anaerobic threshold percent of $VO_2$ max or absolute $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) at anaerobic threshold during the cycle or run protocols.

A significant correlation ($p \leq 0.05$) was found between swim velocity at anaerobic threshold (V-AT) and total time, however, no relationship could be established between cycling or running $VO_2$ at anaerobic threshold ($VO_2$- AT) and total time (Table 4-4). Swim velocity at anaerobic threshold (V-AT) ($p \leq 0.0001$) and heart rate while running at anaerobic threshold (AT-HR) ($p \leq 0.05$) were significantly correlated to swim and run individual event performance, respectively (Table 4-5).

During the three speed swim test the 90% swim velocity elicited a mean lactate value of 4.17 (S.D. 0.46). As this value was close to 4.0 it demonstrates that the possible error in estimating anaerobic threshold through linear interpolation was small.

## Other Predictors

In addition to anaerobic threshold other physiologic variables were examined to demonstrate which could help predict performance. A one factor ANOVA test of repeated measures demonstrated that max heart rate during swimming was significantly lower than max heart rate during cycling or running, however there was no significant difference between the latter two. A paired t-test also demonstrated no significant difference between $VO_2$ max during cycling and running (Table 4-4).

$VO_2$ max during running and cycling was not significantly related to total or specific event performance. Percent body fat also failed to significantly predict total or individual event performance (Table 4-3). Economy measured during the cycle ergometer and treadmill protocols also failed to predict specific event or total performance (Table 4-3).

Best time in the 400 meter swim ($p \leq 0.05$) proved to be a better physiologic predictor of total performance than anaerobic threshold during swimming, however, not quite as good of a predictor of swim performance ($p \leq 0.0001$). Year's in triathlon proved to be the best predictor of total performance ($p \leq 0.01$), and was also highly correlated to swim performance ($p \leq 0.05$) and cycle performance ($p \leq 0.05$).

**Table 4-3. Correlations of selected factors to total and individual event performance (r values).**

| | Total time | Swim time | Cycle time | Run time |
|---|---|---|---|---|
| Total Time | - | 0.739** | 0.935* | 0.555 |
| Body fat | 0.268 | 0.469 | 0.263 | -0.279 |
| Year's in Triathlon | -0.846* | -0.762** | -0.652** | -0.483 |
| $VO_2$ Max (C) | 0.004 | - | -0.010 | - |
| VO2 Max (R) | -0.202 | - | - | -0.308 |
| 400 meter swim best time | 0.734** | 0.959* | - | - |
| Swim Max Lactate | -0.448 | 0.119 | - | - |
| Running Economy | 0.223 | - | - | 0.374 |
| Cycling Economy | -0.150 | - | -0.046 | - |

* $p \leq 0.01$ ** $p \leq 0.05$ (C) = cycle (R) = run

Table 4-4. **Comparison of test results from the three sport protocols.**

| | Cycle Ergometer | Treadmill | 3 Speed Swim Test |
|---|---|---|---|
| $VO_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$) | | | |
| mean | 60.6 | 62.9 | - |
| ±SD | 5.3 | 4.5 | - |
| AT-$VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | | | |
| mean | 45.0 | 50.9 | - |
| ±SD | 7.6 | 5.6 | - |
| AT % of $VO_2$ Max | | | |
| mean | 74.0 | 81.0 | - |
| ±SD | 8.0 | 7.9 | - |
| Max HR | | | |
| mean | $187.5^b$ | $191.5^a$ | 175.2 |
| ±SD | 9.5 | 11.3 | 13.6 |
| AT-HR | | | |
| mean | $155.8^{c,d}$ | $171.6^a$ | 140.5 |
| ±SD | 14.3 | 10.3 | 7.1 |
| Time to exhaustion | | | |
| mean | 22:16 | 21:03 | - |
| ±SD | 1:23. | 2:26 | - |
| 400 meter swim time | | | |
| mean | - | - | 5:54 |
| ±SD | - | - | 0:21 |
| Swim max lactate (mmol/l) | | | |
| mean | - | - | 7.3 |
| ±SD | - | - | 0.9 |

Scheffe F-Test

| | | |
|---|---|---|
| a. run vs swim | Significant | $p \leq 0.01$ |
| b. cycle vs swim | Significant | $p \leq 0.05$ |
| c. cycle vs swim | Significant | $p \leq 0.01$ |
| d. cycle vs run | Significant | $p \leq 0.01$ |

**Table 4-5. Correlations of anaerobic threshold measurements to total and individual event performance (r values).**

| | Total Time | Swim Time | Cycle Time | Run Time |
|---|---|---|---|---|
| AT-vel(S) | -0.686** | -0.964* | -0.481 | 0.050 |
| AT-HR(S) | 0.428 | 0.211 | 0.282 | 0.585 |
| AT-HR(C) | 0.164 | -0.123 | 0.170 | 0.430 |
| AT-HR(R) | 0.198 | -0.390 | 0.316 | 0.706** |
| AT-$VO_2$(C) | -0.066 | 0.046 | -0.037 | -0.219 |
| AT-$VO_2$(R) | -0.224 | -0.412 | -0.049 | -0.010 |

*$p \leq 0.01$ **$p \leq 0.05$
(S) = swim (C) = cycle (R) = running

## Prediction of Performance

Using step-wise regression, equations were developed to predict total performance time as well as swim, cycle and run times.

The best equation to predict total time was:

$$\boxed{\text{Total Time} = 7112.733 + 5.385\ (\text{400 meter swim best time}) - 179.141\ (\text{swim max lactate})}$$

The three individual event times were not entered into this equation because they made up the total time.

Total Time = 7112.733 + 5.385 (400 meter swim best time)
- 179.141 (swim max lactate)

The three individual event times were not entered into this equation because they made up the total time.

The best equations to predict success in the three individual events comprising the total time were:

Swim Time = 2672.451- 1367.114 (anaerobic threshold swim velocity)

Cycle Time = 3242.876 + 2.002 (400 swim best time).

Run Time = 998.064 + 8.891 (run anaerobic threshold heart rate).

# CHAPTER 5: DISCUSSION

## Subject Characteristics

The average age, (27.4 years) height (177.9 cm) and weight (74.8 kg) of athletes in this study are consistent with values reported in other studies of male triathletes (Kohrt et al., 1989; Kreider et al., 1988a; O'Toole et al., 1987b). The average body fat of 9.4% also compares favorably with previous research (Holly et al., 1986; O'Toole et al., 1987b; Roalstad, 1989).

Subjects in this study had competed in triathlons from one to seven years which is consistent with the experience of athletes in previous research, perhaps due to the short existence of the sport (O'Toole et al., 1989; Roalstad, 1989). Years of competition is generally a good predictor of performance as it takes time to develop the cardiovascular and peripheral systems for optimal endurance performance (O'Toole et al., 1989). Our results demonstrated that years of competition in triathlon was significantly correlated with total ($r= - 0.846$) swim ($r= - 0.762$) and cycle ($r = - 0.652$) performance times, however, not with run ($r = -0.483$) time.

Six athletes came from a running background while three came from swimming and one from cycling. This is consistent with previous research as most triathletes come from a running background (Kohrt et al., 1989; O'Toole et al., 1989). Since most of the athletes were initially runners, the athletes with the greatest number of years running were not necessarily in triathlons the longest. This, combined with the effects of previous exercise, may partially explain the low correlation run time had with total time.

## Olympic Distance Performance

An Olympic distance triathlon consists of a 1500 meter swim, 40 km cycle and a 10 km run. Performance times from the July 27th, 1991 Pinawa triathlon demonstrated the athletes were good, however, not elite triathletes. Elite performance times for Olympic distance races vary from one hour and forty eight minutes to just under two hours. Subjects in our study ranged from two hours to two hours and twenty minutes, with a mean time of two hours ten minutes and forty seconds.

External factors such as temperature, wind and difficulty of the race course also effect performance time (O'Toole et al., 1989). The temperature for the Pinawa triathlon was 28 degrees celsius with a relatively light 10 km per hour wind. Water temperature was a cold 18 degrees celsius making wetsuit use compulsory. The swim consisted of a modified triangle and exceptionally fast swim times suggest that the distance may have been 100 to 150 meters short. The cycle course was a flat out and back cycle on a highway which was conducive to fast cycle times. The run course was flat and contained many tight turns through the town of Pinawa, which contributed to run times being slow.

Since event duration varies ( cycle > run > swim ) in a triathlon it was hypothesized that the longer events would correlate more closely to total performance. In our study, cycling (r = 0.935) and swimming (r = 0.739) times were significantly correlated to performance time, while running time (r = 0.555) was not. Previous research into both Ironman (O'Toole et. al. 1987c) and half Ironman (Kohrt et al., 1989; Dengal et al., 1989) triathlons found cycle and run times to be significantly related to performance time, while swimming was not. A possible explanation for our findings may be that swimming comprises approximately 20% of Olympic distance race time while in longer races it only comprises 10% of race time. Swimming is also the most technically demanding of the three sports (O'Toole et al., 1989 ), with wider variation in ability than in running possibly contributing to it's higher correlation with performance time. Cycling makes up approximately 50% of total race time and is logically a better predictor of performance than running and swimming which contribute approximately 30% and 20% of race time, respectively. Climatic conditions may have impacted on the ability of run times to predict total performance., as the weather was hot and dehydration and increases in core temperature may have diminished it's ability to predict total performance. Climatic conditions would have less effect during cycling because of the velocity of the sport which allows the athlete to stay cooler. Also, since the swim was so cold it would have taken a longer time for elevations in core temperatures to have occured.

## Anaerobic Threshold

The primary hypothesis of this study was partially supported as anaerobic threshold swim velocity was the single best physiological predictor of total triathlon performance (r = -0.686). Cycling and running anaerobic threshold failed to predict total performance. The sub hypothesis that anaerobic threshold would predict individual event performance was only demonstrated during swimming (r = -0.964) and not during cycling (r = -0.037) or running (r = -0.010).

Since swimming is the first event in a triathlon it is understandable that the swim results should be similar to previous research designed to evaluate the ability of anaerobic threshold to predict performance in swimming. However, no research to date has confirmed this or evaluated anaerobic threshold swim velocity as a predictor of total triathlon performance. The inability of cycling and running anaerobic threshold to predict triathlon performance indicates that it may not be a good predictor of performance when events are preceded by intense exercise. Factors such as increases in core temperature, dehydration and decreases in mechanical efficiency may result in cumulative fatigue that may effect the ability of anaerobic threshold to predict performance. Since the environmental conditions (28 degrees celsius) were so extreme and the effort level was maximal, increases in core temperature and dehydration definitely occured. Saltin (1964) demonstrated that dehydration lowers lactate levels in the blood. This lowering of lactate levels with dehydration may have impaired the ability of anaerobic threshold to predict triathlon performance. Since the race took place in a field setting it is difficult to determine exactly the extent of dehydration and elevation in core temperature that took place. However, a laboratory simulated triathlon (Kreider et al., 1988a) conducted in a similar environment but at a lower intensity resulted in a 2.7 degree celsius elevation in core temperature and a 3% loss in body weight due to dehydration. Since the conditions were similar in the two studies, equal or greater increases in core temperature and levels of dehydration probably occured.

Increased levels of dehydration and elevation in core temperature contribute to cumulative fatigue resulting in a decrease in mechanical efficiency. It is this decline in mechanical efficiency which may limit the ability of anaerobic threshold to predict triathlon performance.

Previous conflicting results about whether anaerobic threshold can predict triathlon performance may only partially be the result of race distance. Environmental conditions may play as important a role because of their role in effecting mechanical efficiency. This hypothesis is supported by O'Toole et al. (1987b) who concluded anaerobic threshold is a poor predictor of triathlon performance under the severe environmental conditions of the Hawaii Ironman, and Kohrt et al. (1989) who found anaerobic threshold a good predictor of triathlon performance during a half Ironman triathlon in a less severe environment. More research must be done on races of various distances and during varied environmental conditions to better understand the value of anaerobic threshold as a predictor of triathlon performance.

Another possible contributing factor for conflicting findings on whether anaerobic threshold can predict triathlon performance is the subject population. In both our study and in O'Toole et al. (1987b) where negative findings were reported the subject population was very homogeneous while in Kohrt et al. (1989) study which suggested anaerobic threshold was a good predictor the subject group was much more heterogeneous possibly magnifying any predictive ability anaerobic threshold had.

Anaerobic threshold expressed as percent of $VO_2$ max was not significantly different during the cycle (74%) or run (81%) protocols. This differs from results on single sport athletes who have a significantly higher percent $VO_2$ max in their primary sport (Costill et al., 1973). Previous research has demonstrated anaerobic threshold to be sport specific in triathletes. While some cross training benefits have been shown to occur in sport specific $VO_2$ max values with triathlon training. Since our results failed to demonstrate a significant difference in anaerobic threshold running and cycling, one could suggest the athletes may be of a comparable fitness level in the two sports.

## Maximal Oxygen Uptake

$VO_2$ max values from our study fell within the range of previous studies as treadmill and cycle ergometry values were 62.9 and 60.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. This represents a 3.7% difference in maximal aerobic power between the two modes and supports previous triathlon research which has shown cycling $VO_2$ max to be 3 - 6% less than running. These results differ from studies on single sport athletes which have demonstrated runners to have a $VO_2$ max from 9 to 11% higher on the treadmill than the cycle ergometer, and cyclists to have a similar, if not a slightly higher, $VO_2$ max on the cycle ergometer (O'Toole et al., 1989). Single sport athletes tend to have higher maximal oxygen uptake's in their primary sport than the sports they don't do, therefore triathletes who train all three sports obtain higher $VO_2$ max on the other two sports than the single sport athlete's explaining these findings.

In the present study the sub hypothesis that maximal oxygen uptake during the running and cycling tests would predict individual event or total performance was rejected. $VO_2$ max during cycling was found to have correlations of r=

0.010 and 0.004 with cycling and total time, $VO_2$ max while running on the treadmill had correlations of r= -0.308 and -0.202 with running and total time, respectively.

In individual endurance events such as swimming, cycling, and running, $VO_2$ max is inversely related to race performance in heterogeneous groups of athletes (Costill et al., 1973; Farrell et al., 1979; Krebs et al., 1966). The correlations between $VO_2$ max and race finish times are consistently close to r = -0.9 for 10 km runners and 1500 meter swimmers, and r = - 0.45 to -0.87 in 40 km cyclists (Farrell et al.,1979; Krebs et al., 1966; O'Toole et al., 1989).

Several factors such as cumulative fatigue, dehydration and elevation in core temperature act to decrease mechanical efficiency which may contribute to $VO_2$ max inability to predict performance. It is believed that $VO_2$ max sets a genetic limit on the maximal volume of oxygen the body can utilize during exercise and it is the submaximal percentage of this volume that the body can maintain during continuous exercise which determines an athletes endurance performance. Therefore, $VO_2$ max is a measure of maximal power of the aerobic system while performance is dictated by the aerobic capacity or submaximal percentage an athlete can maintain for the duration of a race.

## Heart Rate and Triathlon Performance

Heart rate at anaerobic threshold was significantly different during each individual event of the triathlon. Heart rate at anaerobic threshold while cycling (155.8) was significantly higher than swimming (140.5) however, significantly lower than running (171.6). Our results support previous research (O'Toole et al., 1989; Kohrt et al., 1989) that anaerobic threshold is sport specific. This finding is significant for training program design. It demonstrates that sport specific protocols must be prescribed for each sport to determine optimal training intensities and that the optimal training intensity or heart rate in one sport may not be the same as in another.

Max heart rate during swimming was significantly lower than during cycling or running while no significant difference was shown to exist between cycling and running. This can be explained by the horizontal body position during swimming which aids in the return of blood to the heart resulting in a lower maximal heart rate.

## Running and Cycling Economy and Triathlon Performance

Our findings failed to demonstrate either running economy (r = 0.374, 0.223) or cycling economy (r = -0.460, -

0.150) as good predictors of individual event (r = 0.374, -0.460) or total performance (r = 0.223, 0.150), respectively. Although running economy did not significantly predict triathlon run time, its relationship (r = 0.374) compared favorably with previous running research (Farrell et al., 1979, Daniels et al., 1977) on homogeneous athletes. A possible explanation for economy not being able to predict performance may be that the sample group was too homogeneous in ability for economy to be a significant predictor. Other reasons may be due to test design. One could argue against the validity of comparing test results from an individual sport protocol with race results in a fatigued state. Also, due to the short duration of the stages (3 minutes) there is some question as to whether a true steady state was achieved at the submaximal workload.

Environmental factors may play a role in the ability of economy to predict triathlon or specific event performance. Dehydration is one variable known to decrease mechanical efficiency. Losses of 3% body weight have been reported (Kreider et al., 1988a) under similar laboratory simulated environmental conditions as in our study. Since our subjects were chosen after the running of the race it was not possible to measure losses in body weight. In both races water was taken ad libitum during the cycle and run. Weight losses of 3% due to dehydration have been demonstrated to severely diminish performance levels.

Increases in core temperature may have also influenced the response of athletes in the present study. In a simulated triathlon (Kreider et al., 1988a) conducted under similar environmental conditions core temperature was demonstrated to rise from 37.0 degrees celsius to 39.7 degrees celsius. Since our study was conducted at actual race intensity, and the simulated triathlon at a lower intensity, a greater elevation in core temperature may have occured during our study. These factors likely acted to decrease the importance of economy in predicting triathlon performance.

## Body Composition and Triathlon Performance

Percent body fat had nosignificant relationship with total triathlon performance time (r = 0.268), swim, (r = 0.469) cycle (r = 0.263) or run (r = -0.279) time. A possible explanation for the inability of percent body fat to predict triathlon performance is the homogeneous subject group in the study. Our subjects had a mean body fat percentage of 9.4% with very little individual variation. Perhaps if the sample group had been more heterogeneous among subjects a higher correlation may have occured. Also since the test is believed to be only accurate to within 3% body fat the homogeneity of the study makes it difficult to predict performance. It is also probable that as environmental problems, such as dehydration and elevated core temperatures, increase in importance for predicting triathlon performance other factors such as anaerobic threshold and percent body fat decrease in value.

## Prediction of Olympic Distance Triathlon Performance

Equations were developed to help determine which variables aided in the prediction of total and individual event performance. Swim variables were found to be the most useful for the prediction of total time as well as swim and cycle performance. Swimming is the first event in a triathlon, therefore cumulative fatigue or increases in core temperature are likely to have less impact on swimming performance.

Four hundred meter swim best time proved to be the best predictor for cycle and total time. Slower swimmers may suffer greater thermoregulatory and cardiovascular changes than faster swimmers which may effect cycle performance and total time. Slower swimmers also tend to be less efficient than faster swimmers and may use more energy to finish the swim which may result in a decrease in mechanical efficiency during the cycle due to fatigue.

Anaerobic threshold swim velocity proved to be the best predictor of swim performance. In individual endurance sports such as swimming, anaerobic threshold has been demonstrated to be the single best predictor of endurance performance. (Costill & King, 1983; Maglischo et al., 1984). Since swimming is the first event in a triathlon and no cumulative fatigue has occured there is every reason to believe this relationship should continue to exist.

Heart rate at anaerobic threshold was found to be the best predictor of run performance. This relationship demonstrates athletes whose anaerobic threshold occured at a lower heart rate had faster run times. Since heart rate at a given intensity increases in proportion with the environmental temperature athletes with lower heart rates at anaerobic threshold may perform better during extreme heat because their elevated heart rate at anaerobic threshold is still below max heart rate while athletes whose heart rate at anaerobic threshold is higher may be limited by their max heart rates. Athletes with higher anaerobic threshold heart rates may not be able to meet this new elevated anaerobic threshold heart rate during extreme environmental conditions.

## Summary and Conclusions

The purpose of this thesis was a) to determine which variables are important for the prediction of triathlon performance ; and b) to develop prediction equations from the variables studied to predict swim, cycle, run and total triathlon performance.

Ten male subjects aged 21-36 participated in the study. Each subject completed an anaerobic threshold / $VO_2$ max protocol on both a cycle ergometer and a treadmill. The subjects also underwent a hydrodensitometry test for the determination of percent body fat and a three speed swim test for the determination of anaerobic threshold. The results of these tests were entered into a correlation matrix with performance splits and total triathlon time from an Olympic distance race.

The results of this study demonstrated that anaerobic threshold swim velocity was a significant predictor ($p \leq 0.05$) of total performance, while cycling and running $VO_2$ at anaerobic threshold failed to significantly predict total performance.

Swim velocity at anaerobic threshold proved to be the best predictor ($p \leq 0.01$) of swim performance while cycling and running $VO_2$ at anaerobic threshold failed to significantly predict cycle and run performance, respectively.

Maximal oxygen uptake and percent body fat failed to predict total performance time or time of any of the individual events. Cycling and running economy also failed to predict total or individual event performance. These findings differ from results on single endurance sports where these variables have been shown to correlate highly with performance. These results suggest cumulative fatigue diminishes the ability of anaerobic threshold, maximal oxygen uptake, percent body fat and economy to predict triathlon performance.

Of all the variables studied, years of triathlon experience proved to be the best predictor ($p \leq 0.01$) of total triathlon performance. This finding demonstrates the importance of specificity. If the factors that determine triathlon performance are different than the factors that determine individual endurance sport performance, it is logical to assume athletes who have trained longer will have an advantage in dealing with decreases in mechanical efficiency that the cumulative nature of the sport may cause.

These conclusions indicate that the factors that predict Olympic distance triathlon performance differ from those that predict single sport endurance performance. The results suggest factors that lead to cumulative fatigue may be the major determinant in Olympic distance triathlon performance.

## Recommendations for Training and Racing

1. Anaerobic threshold as demonstrated in our study is sport specific. Therefore, to be successful in triathlons athletes must train each modality and place an emphasis on their weakest sport.
2. Triathletes should set up their training intensities based on sport specific tests and not extrapolate data from one sport to estimate training intensities for another.
3. Years of experience in triathlons was demonstrated to be the best predictor of Olympic distance triathlon performance. This finding suggests the factors that determine performance are trainable and may be unique to this sport.
4. Heart rate at anaerobic threshold proved to be the best predictor of run performance, suggesting athletes with lower

heart rates at anaerobic threshold may have an advantage in dealing with extreme environmental conditions.

## Possible Limiting Factors
## “Areas for Further Research”

The major finding of this thesis demonstrated anaerobic threshold, maximal oxygen uptake and percent body fat are not good predictors of triathlon performance. However, although this thesis doesn’t demonstrate what does predict performance it does suggest possible factors which may limit performance and areas for further research.

Factors that limit Olympic distance triathlon performance (Figure 5.1) may occur due to the cumulative nature of the sport. This continuous nature may result in cumulative fatigue that can decrease mechanical efficiency and result in an increase in core temperature decreasing performance. Dehydration is another variable believed to possibly limit performance.

Much research must be performed to evaluate if and to what extent cumulative fatigue, decreases in mechanical efficiency, increases in core temperature and dehydration effect performance. If these factors do determine performance athletes may take several steps to diminish the effects of these variables.

1. The maintenance of mechanical efficiency is critical to performance. Training programs should be designed to teach the body how to deal with cumulative fatigue.

2. To help prevent a breakdown in efficiency an athlete should incorporate long single sport workouts into their training program. By performing these workouts the specific event muscle group will become stronger making it more resistant to fatigue which results in a decline in muscle function which is believed to cause a decrease in mechanical efficiency.

3. A good weight program may also diminish the effects of cumulative fatigue. By strengthening the sport specific muscle groups the athletes are able to cope with greater cumulative fatigue before decreases in mechanical efficiency occur.

4. Triathletes should be aware of the psychogenic and thermal demands of performing the later segments of the triathlon and plan their training accordingly. Therefore, triathletes should occasionally train the events in succession in order to simulate the physiologic responses experienced during prolonged triathlon performance.

5. Triathletes must attempt to prevent an elevation in core temperature, thereby attenuating the thermoregulatory changes which result in altered cardiovascular responses. Drinking regularly and wetting the body regularly with a sponge are useful in preventing an elevation in temperature and dehydration.

6. Triathletes should ingest fluids frequently throughout a triathlon in an attempt to maintain hydration and to minimize the elevation in core temperature, possible fluid shifts, dehydration and impaired performance. Athletes should practice drinking in training so that they will be accustomed to taking on fluid in races.

7. To adapt to the increased thermoregulatory and cardiovascular demands during triathlon performance athletes should do some workouts during the hottest part of the day. By running hard in the heat an athlete may help accustomize themselves to running with an elevated core temperature which would simulate physiological responses which occur during triathlon performance.

8. Experience is critical in allowing athletes to judge physiologic effort and alter work output in conjunction with decreased metabolic and mechanical efficiency precipitated by elevations in core temperature and dehydration during triathlons. The serious triathlete should do early season races to prepare themselves to the physiologic demands that will be placed upon them during major competition and to help them learn what level of work output they can maintain during races.

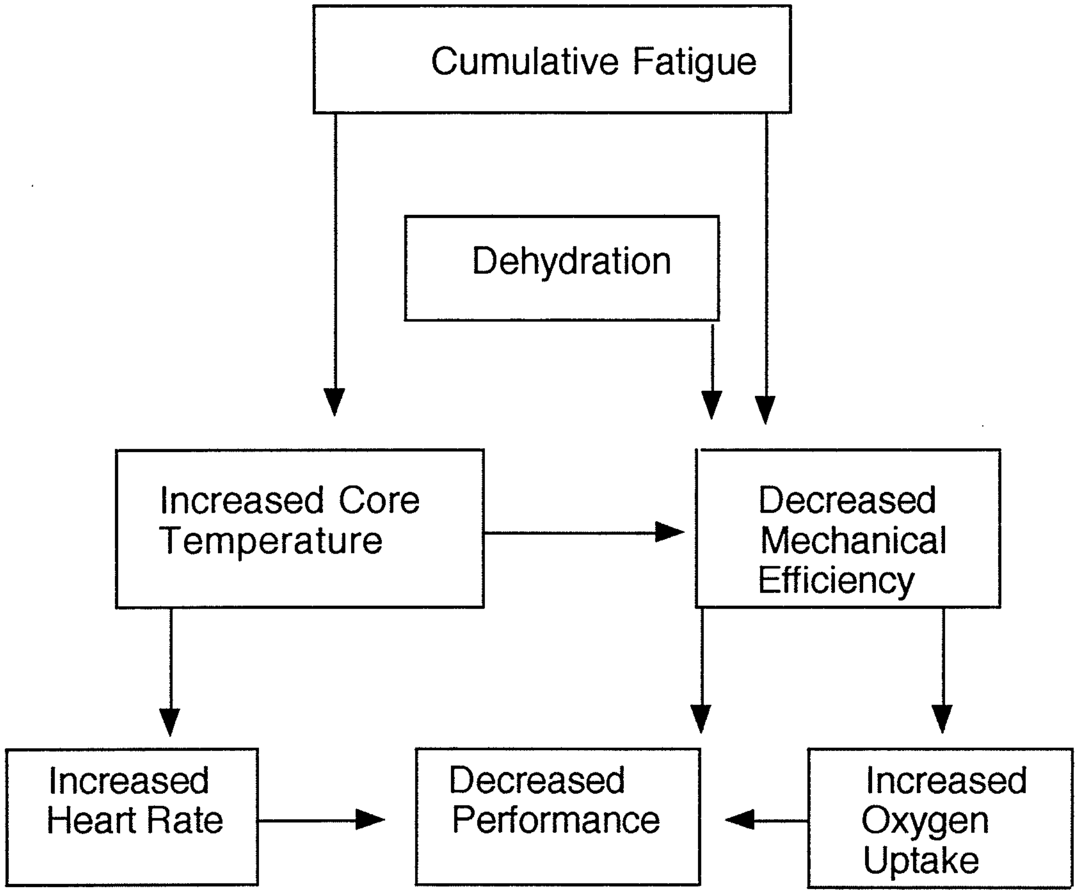

**Figure 5.1. Possible limiting factors in olympic distance triathlon performance**

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# Appendix A

## Thesis Tests

TESTING:

#1: OLYMPIC DISTANCE TRIATHLON (PINAWA)

#2: BODY COMPOSITION (HYDROSTATIC WEIGHING)

#3: TREADMILL PROTOCOL ($VO_2$ Max, Anaerobic Threshold)

#4: CYCLE ERGOMETER PROTOCOL ($VO_2$ Max, Anaerobic Threshold)

#5: 3 Speed Swim Test (Anaerobic Threshold)

INSTRUCTIONS:

- Subjects should avoid caffeine 3 hours prior to tests 3-5.
- Subjects shouldn't do strenuous activity within 48 hours of tests 3-5.
- Subjects shouldn't do physical activity within 24 hours of tests 3-5.
- Subjects should stretch and do a prescribed warm up prior to each test.

TREADMILL AND CYCLE ERGOMETER:

15 MINUTE WARM UP (SPORT SPECIFIC) + STRETCHING

SWIM:

800 SWIM WARMUP + 4 X 50 METERS ON 1:15(MODERATE)

# Appendix B

## ANAEROBIC THRESHOLD, VO2 MAX AND PERCENT BODY FAT AS PREDICTORS OF OLYMPIC DISTANCE TRIATHLON PERFORMANCE

SPORT AND EXERCISE SCIENCES
RESEARCH INSTITUTE
UNIVERSITY OF MANITOBA

### 1. EXPLANATION OF STUDY

It has been demonstrated in swimming, cycling and running that anaerobic threshold and VO2 Max are highly related to race performance. Research into ultraendurance triathlons have failed to support this finding. However, no research to date has evaluated these items ability to predict race performance at Olympic Distance Triathlons.

Thus, the purpose of this study is to determine the extent that anaerobic threshold, maximum oxygen uptake and percent body fat contributes to the prediction of Olympic Distance Triathlon performance.

### METHODS AND PROCEDURES

The study will consist of ten male triathletes aged 18 to 39 years of age. To be eligible for the study a male participant must have completed an Olympic Distance Triathlon in 2 hours 20 minutes or less.

### PHYSIOLOGICAL TESTS

1. Treadmill ( VO2 Max Protocol )

Participants will undergo a incremental test to volitional exhaustion on a motor driven treadmill. This test will require you to wear a nose plug and breathe through your mouth. The total time required for this test will be 30 minutes. You will be required to follow a prescribed taper three days prior to this test.

2. Cycle Ergometer ( VO2 Max Protocol )

Will follow the same procedure as the treadmill ( VO2 Max Protocol ).

This test will be 30 minutes in duration and a prescribed taper for 3 days prior to this test will be required.

3. Three Speed Swim Test

You will complete three 400 meter swims at 80%, 90% and 100% effort with a 20 minute rest between efforts.

This test will be of approximately one hour duration and you are required to follow a prescribed taper 3 days prior to testing. Blood samples will be obtained by a qualified target fitness appraiser.

**BLOOD LACTATE ANALYSIS**

In each of the first three tests blood samples of 25 microliters will be taken from the finger tip for the determination of lactate acid levels.

4. Body Composition

You will undergo a hydrodensitometry test ( underwater weighing ) for the determination of percent body fat. This test will involve staying under water for a short period of time.

5. Olympic Distance Triathlon

You will undergo an Olympic Distance Triathlon for the determination of swim, cycle, run, and total times. All subjects must taper for the event.

**RISKS**

During the treadmill test - possible dizziness, nausea, or slight cardiac abnormalities may occur.

Sport & Exercise Sciences Research Institute
University of Manitoba

## Consent Form

### Anaerobic Threshold, VO2 Max and Percent Body Fat as Predictors of Olympic Distance Triathlon Performance

I have read the description of the study and understand the measurement procedures involved.

I also understand that my participation in this study is voluntary and that I may withdraw from it at any time without prejudice.

All information will be kept confidential.

I understand that participation in this research study is done at my own risk and hereby release the University of Manitoba, their agents, officers, and employees from any liability, with respect to any damage or injury ( including death ) that I may suffer during my participation in the research study.

| | |
|---|---|
| ____________________ | __________________________ |
| DATE | PARTICIPANT |
| ____________________ | __________________________ |
| DATE | WITNESS |

# Appendix C

## ESTIMATION OF % FAT BY DENSITOMETRY

1. Fill tank with water (36 degrees C + 1 degree C).

2. Weigh subject and recor weight

3. Have subject enter tank and stand on platform; explain procedure; install chest harness and adjust rope length.

4. Have subject take 3 deep breaths, exhale completely and gently submerge until the slack in the rope in completely taken up. Subject then gently raises feet off the bottom, remaining in "hung" position and avoiding contact with the tank.

5. Record the reading of the weigh scale as soon as the indicator has stopped or remains oscillating around a fixed value.

6. Signal subject to emerge by tapping on tank.

7. Repeat steps #5 - #7 until two identical (to nearest 0.01 kg.) and highest readings are obtained. Record reading. Remove chest harness

9. Perform a vital capacity test. Repeat twice and record highest score.

# Appendix D

THESIS 3 SPEED SWIM PROTOCOL

3 X 400 METERS AT 80%, 90%, 100%

Name:________________________
Date:__________________________
Pre Exercise H.R.:__________ Pre exercise Lactate:_________
Weight:_________ Test#:__________ 400 P.R.:________

| | TIME | H.R | LACTATE |
|---|---|---|---|
| 1. 400 METERS AT 80% | ______ | ______ | _________ |
| 2. 400 METERS AT 90% | ______ | ______ | _________ |
| 3. 400 METERS AT 100% | ______ | ______ | _________ |

Max H.R.:_________ AN. THRESHOLD H.R.:_________
Best 400:__________ AN THRESHOLD VELOCITY:________

# Appendix E

## ANAEROBIC THRESHOLD
## MAXIMAL OXYGEN UPTAKE
## CYCLE ERGOMETER PROTOCOL

Name:______________________________

Date:______________________________

Pre exercise H.R.:__________ Pre exercise Lactate:________________

Weight:_________________ Test #:____________

Lab temp.:_______ Barometric Pressure:___________ B.P.__________

| STAGE<br>(#) | RESISTANCE<br>(K.P) | TIME<br>(MIN.) | H.R.<br>(B.P.M.) | $VO_2$<br>(ml.kg.min.) | LACTATE<br>(mM litre) |
|---|---|---|---|---|---|
| 1 | 1.5 | 0-3 | ______ | ________ | _________ |
| 2 | 2.0 | 3-6 | ______ | ________ | _________ |
| 3 | 2.5 | 6-9 | ______ | ________ | _________ |
| 4 | 3.0 | 9-12 | ______ | ________ | _________ |
| 5 | 3.5 | 12-15 | ______ | ________ | _________ |
| 6 | 4.0 | 15-18 | ______ | ________ | _________ |
| 7 | 4.5 | 18-21 | ______ | ________ | _________ |
| 8 | 5.0 | 21-24 | ______ | ________ | _________ |
| 9 | 5.5 | 24-27 | ______ | ________ | _________ |
| 10 | 6.0 | 27-30 | ______ | ________ | _________ |
| 11 | 6.5 | 30-33 | ______ | ________ | _________ |
| 12 | 7.0 | 33-36 | ______ | ________ | _________ |

"Supermaximal $VO_2$" #1:______________

#2:______________

#3:______________

Max. H.R.:_________ AN.THRESHOLD H.R.:____________

AN.T.STAGE#:_________ Max. $VO_2$:______________

Efficiency $VO_2$ Stage #5:__________ Stage#7:____________

Time to exhaustion:_______________

# Appendix F

## ANAEROBIC THRESHOLD
## MAXIMAL OXYGEN UPTAKE
## TREADMILL PROTOCOL

Name:______________________________

Date:______________________________

Pre exercise H.R.:____________ Pre exercise Lactate:__________________

Weight:__________________ Test #:____________

Lab temp.:______ BAROMETRIC P.:________ BLOOD P.:__________

| STAGE | SPEED | GRADE | TIME | H.R. | $VO_2$ | LACTATE |
|---|---|---|---|---|---|---|
| (#) | (M.P.H) | (%) | (MIN.) | (B.P.M.) | (ml.kg.min.) | (mM litre) |
| 1 | 6.0 | 0 | 0-3 | ______ | ________ | __________ |
| 2 | 7.0 | 0 | 3-6 | ______ | ________ | __________ |
| 3 | 8.0 | 0 | 6-9 | ______ | ________ | __________ |
| 4 | 8.0 | 2.5 | 9-12 | ______ | ________ | __________ |
| 5 | 8.0 | 5.0 | 12-15 | ______ | ________ | __________ |
| 6 | 8.0 | 7.5 | 15-18 | ______ | ________ | __________ |
| 7 | 8.0 | 10.0 | 18-21 | ______ | ________ | __________ |
| 8 | 8.0 | 12.5 | 21-24 | ______ | ________ | __________ |
| 9 | 8.0 | 15.0 | 24-27 | ______ | ________ | __________ |

"Supermaximal $VO_2$" #1:______________

#2:______________

#3:______________

Max. H.R.:_________ AN.THRESHOLD H.R.:____________

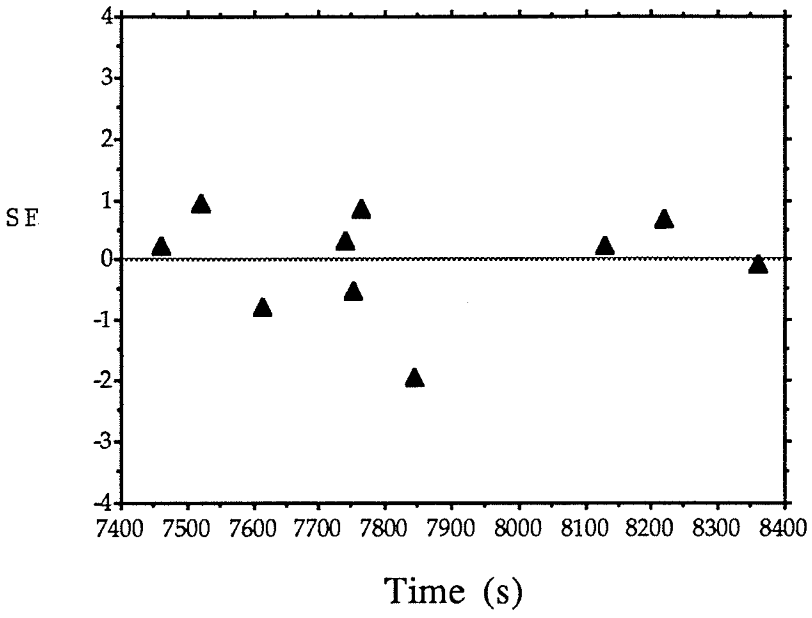
AN.T.STAGE#:_________ Max. $VO_2$:________________

Efficiency $VO_2$ Stage #3:____________ Stage#5:______________

Time to exhaustion:________________

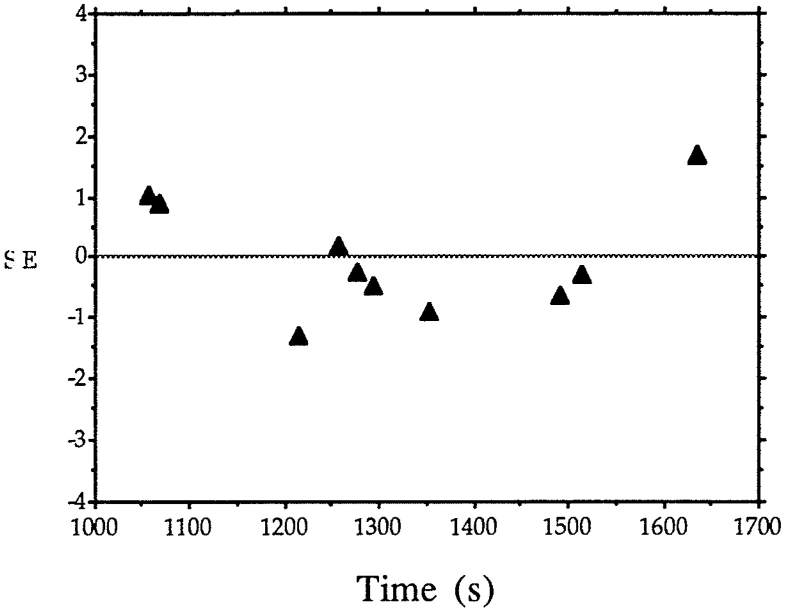
# Appendix G (1)

Test of assumptions for prediction equation for total time



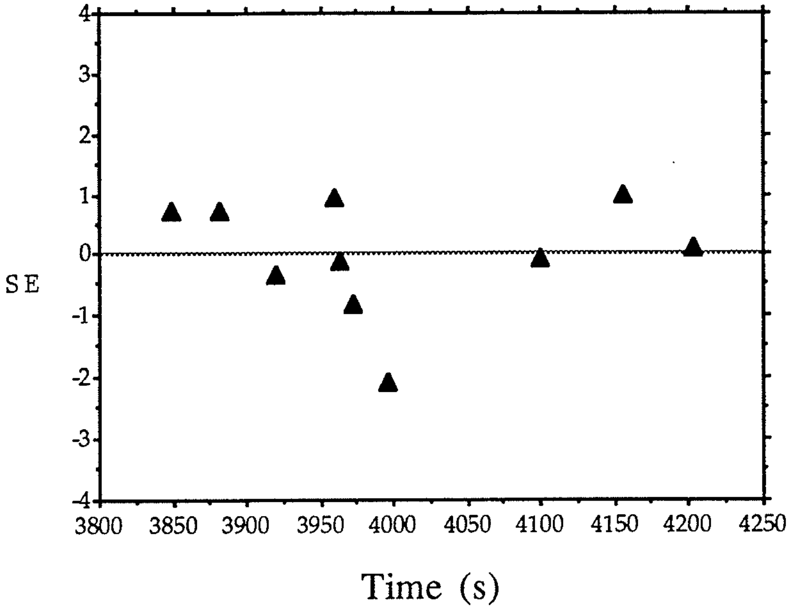
# Appendix G (2)

Test of assumptions for prediction equation for swim time



# Appendix G (3)

Test of assumptions for prediction equation for cycle time



# Appendix G (4)

Test of assumptions for prediction equation for run time