Swimming Economy in Long Distance Swimmers and Ironman Triathletes

THESIS

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By

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Abstract

Participation in the Ironman Triathlon has increased rapidly since its inception in 1978 (Lepers, R., 2008). The inherent cross-training in triathlon limits optimization of performance in a single discipline (Millet, G. P., et al. 2002). Swimming requires more specificity of training than running or cycling as it is more dependent upon technique (Millet, G. P., et al. 2002; Zamparo, et al., 2010). Though Toussaint (1990) showed a decrease of propelling efficiency between swimmers and triathletes; this study tested short distance triathletes and swimmers. While elite Ironman Triathletes swam the Hawaii Ironman 10% slower than elite Long Distance Swimmers swam the Waikiki Roughwater Challenge; comparisons should not be made on time race time alone (Lepers, R., 2008). Several authors have reported swimming economy, as quantified by energy cost (EC) of locomotion as the best performance determinant in terrestrial and aquatic environments (di Prampero, P.E., 1986; Capelli, P., et al. 1995; Zamparo, et al., 2005). Zamparo (2005) found EC increased and stroke mechanics decreased at the end of a long distance swim in elite Long Distance Swimmers. However, Long Distance Swimmers and Ironman Triathletes have not been compared, nor have Ironman Triathletes been evaluated, on the economy and mechanics of long distance swimming. PURPOSE: To compare the economy and stroke mechanics; stroke frequency (SF) and stroke length (SL), of Long Distance Swimmers and Ironman Triathletes before and after an 1829-m swim. METHODS: 6 (4 female, 2 male) well-trained Long Distance
Swimmers (S) and 8 (all male) well-trained Ironman Triathletes (T) were tested on 2 separate sessions; Baseline-Familiarization (BF) and Experiment (E). The BF included a body composition test, 365.8-m swim at competition pace to establish pacing during the E and familiarization to the E protocol. Subjects returned within 7 days for the E where they swam 3x365.8-m (PRE), 1x1829-m (LONG) and 3x365.8-m (POST) at paces reflective of Ironman or 3K open water competition pace. Economy was quantified by EC (kJ/m); the ratio of total energy expenditure (Et) to pace. Et was calculated from the summation of anaerobic and aerobic energy expenditure as measured by lactate and VO$_2$, immediately and 60-sec after each swim (di Prampero, P.E., et al., 1976; Montpetit, R., et al., 1981; Costill, D.L. et al., 1985; Zamparo, et al., 2005). Immediately upon obtainment of 60-sec of breath by breath VO$_2$ data, subjects resumed swimming until completion of the protocol. VO$_2$ was determined by the back extrapolation method. SF and SL were determined from video analysis. RESULTS: S, compared with T, had significantly lower pace and energy cost in the PRE and POST swims (p<0.05). T, on the POST compared with the PRE swims, exhibited a significant decrease in stroke length.

CONCLUSION: Long Distance Swimmers, compared with Ironman Triathletes, are more economical at swimming and more capable of maintaining stroke mechanics at the end of a long swim.
This document is dedicated to the DiGeronimo Family and Ricky.
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Publications

Abstracts


Fields of Study

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Chapter 1: Introduction

The sport of triathlon, consecutive swimming, cycling and running, is rapidly growing amongst elite and recreational triathletes (Millet, G. P., Bentley, D. J., and Vleck, V. E., 2007; O’Toole, M. and P. Douglas, 1995). Within the sport, races of shorter (Sprint Triathlon) and longer distances (Ironman Triathlon) are held. The Ironman Triathlon is an ultraendurance event taking the fastest competitors 8 to 9 hours to complete and the slowest competitions 16 to 17 hours to complete (Lepers, R., 2008). Lepers (2008) analyzed the Hawaii Ironman, the Ironman World Championships, between 1981 and 2007 and found performance times significantly decreased through the late 1980s, attributable to increased participation as well as to improvements in training and sport technologies (ie. aerobars in cycling). Yet, since the late 1980’s, performance times in the Ironman World Championships have reached a plateau while a high injury rate has plagued the sport (Egermann, M., et al. 2003; Lepers, R., 2008). Such findings necessitate improvements in Ironman training and competition.

The physiological profile of the triathlete has been well studied (Bentley, D.J. et al., 2008, 2002), providing evidence that the maximal aerobic capacity, lactate threshold and economy of motion of triathletes is similar to that of the single sport counterparts (swimmers, cyclists, runners) of triathletes. However, sport-specific studies have found triathletes exhibit a greater inefficiency of pedaling in relation to cyclists (Chapman,
A.R., et al., 2007) and decreased propelling efficiency when compared to swimmers (Toussaint, H.M., 1990). The inability of triathletes to optimize performance within each discipline of triathlon can be in part due to the inherent cross-training present in triathlon training and competition which limits the specificity applied to each individual discipline (Millet, G. P., et al. 2002).

Swimming, compared with running and cycling, is the most specific event as it is highly dependent upon technique (Millet, G. P., et al. 2002; Zamparo, P., C. Capelli, and D. Pendergast, 2010). In triathlon, the distances are least advantageous towards the swimmer as the swim in the Ironman Triathlon constitutes just 10% of the overall race (Laursen, P.B., E.C. Rhodes and R.H. Langill, 2000). Nevertheless, the preceding swim is deemed important due to its contributing effects on eventual performance decrements which occur during the ensuing cycle and run (Palmer et al., 2009, Bentley, D. J., et al. 2002). Although, Laursen (2000) showed prior 3000-m swimming had no effect on 3-hr of subsequent cycling; this study did not evaluate metabolic or mechanical changes in the swim.

Swimming economy, as quantified by units of energy cost, has been described as the best physiological determinant of performance in terrestrial and aquatic environments (di Prampero, 1986; Capelli, P., et al. 1995; Zamparo et. al 2005). Barbosa (2010) has illustrated the influence of metabolic and mechanical parameters on overall swim performance. In a study by Zamparo (2005), elite Long Distance Swimmers increased energy cost and decreased stroke length at the end of a long swim. This type of analysis
has not been performed on Ironman Triathletes. Furthermore, only a comparison of race
times has been made between Ironman Triathletes and Long Distance Swimmers.
Thereby, the aims of this study are to to evaluate the metabolic and mechanical changes
which occur over the course of a long distance swim in Ironman Triathletes and to
compare them with Long Distance Swimmers.

Definitions and Terms of significance

_Triathlon:_ A multisport form of endurance competition which includes consecutive
swimming, cycling and running of various distances. Popularity of triathlon has grown
amongst elite and recreational participants since the sports relatively recent inception in
the 1970s (Millet, G. P., Bentley, D. J., and Vleck, V. E., 2007; O’Toole, M. and Pamela
Douglas, 1995).

_Ironman Triathlon:_ The longest of the four standard distances in triathlon. The Ironman
competition is comprised of a 3.8-K swim, 180-K cycle and 40-K run. Finishing times
range between 8 and 17 hours for elite and recreational participants, respectively. Kona,
Hawaii is the site of the Ironman World Championships (Lepers, R., 2008).

_VO2:_ Volume of oxygen; an integrative measure of oxygen consumption which is
indicative of aerobic capacity. The body consumes oxygen to generate ATP for
translation into energy for movement. VO$_2$ can be measured through indirect calorimetry (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5$^{th}$ Ed.). When measured at maximal physical performance in a mode which recruits a high proportion of muscles mass and is specific to the competition discipline, VO$_2$ is highly predictive of endurance performance (Bentley, D.J. et al., 2008, 2002).

*Lactate*: An anion formed through anaerobic glycolysis when oxygen supply is limited. In a non-steady state, oxygen demand is greater than the supply; consequently, free H$^+$ molecules join with pyruvate to form lactate through the enzymatic action of lactate dehydrogenase. Lactate is shuttled from the working muscles where it is produced to the heart and type I muscle fibers where it is consumed for energy. Thus, lactate is an anaerobic energy source. But, when lactate appearance exceeds disappearance, the low pH associated with lactate accumulation, results in eventual fatigue (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5$^{th}$ Ed.).

*Swimming economy*: The amount of metabolic work required to maintain a given swimming velocity (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5$^{th}$ Ed.). Economical swimming is characterized by the ability to work minimally at a fast and consistent pace. Swimming economy can be quantified through the determination of energy cost (kJ/m) by summating the aerobic (measured by VO$_2$) and anaerobic (measured by lactate) energy equivalents and dividing by pace of the swim (di Prampero, 1986; Capelli, P., et al. 1995; Zamparo, et. al 2005).
*Stroke Frequency*: A mechanical stroke parameter of swimming commonly assessed. Stroke frequency is interrelated with stroke length and velocity through the equation: 

velocity = stroke frequency x stroke length. With the advent of fatigue, to maintain pace, swimmers typically decrease stroke length and increase stroke frequency. Stroke frequency is measured as number of strokes per minute (Millet, G. P., et al. 2002; Zamparo et. al 2005).

*Stroke Length*: A mechanical stroke parameter of swimming commonly assessed as a measure of propelling efficiency (Barbosa, T. M., et al. 2010). Increased stroke length is a characteristic of improvement in swimming. Like stroke frequency, stroke length can be described by the equation: velocity = stroke frequency x stroke length. Stroke length is measured as distance in meters per stroke (Millet, G. P., et al. 2002; Zamparo et. al 2005).
Chapter 2: Literature Review

The sport of triathlon consists of sequential swimming, cycling and running of various distances. Distances are generally classified as Short Distance (Sprint & Olympic) or Long Distance (Half-Ironman & Ironman) with each respective distance increasing in total distance and duration. The longest distance, the Ironman, is comprised of a 3.8-km swim, 180-km cycle and 42-km run. Elite competitors will finish this race in approximately 8 hours whereas less trained individuals can take 17 hours to complete (Bentley, D. J., and D. Bishop. 2008; Lepers, 2008). In 1978, the first Ironman was held in Honolulu, Hawaii with 12 male competitors. In 2007, the Hawaii Ironman Triathlon, serving as the Ironman World Championship, had 1,700 triathlete (~27% females) participants (Lepers, R., 2008). This relatively new sport has grown rapidly, presenting physiological challenges affecting elite and novice triathletes (Neubauer, Konig & Wager, 2008).

Determinants of Triathlon Performance

Triathlon presents a unique physiological challenge. Triathletes must train for three events in isolated and correlated sessions. Yet, the physiological prerequisites for success in triathlon are similar to those of other endurance sports. The measures of VO₂ max, fractional utilization and economy of motion are key variables to overall
triathlon performance (O’Toole, M. and P. Douglas, 1995). VO2 max or maximal oxygen consumption indicates cardio respiratory fitness as it is dependent upon cardiac output and the working skeletal muscles ability to utilize oxygen for aerobic energy. The VO2 maximum values of elite triathletes are approximately 75 ml/Kg/min and 65 ml/Kg/min for males and females, respectively. Treadmill running produces the highest VO2 maximum in triathletes with cycling and swimming, respectively, falling 3-6% and 13-18% lower (O’Toole, M. and P. Douglas, 1995). While single sport specialists have been found to possess higher VO2 maximums within their respective sport; the VO2 maximums of triathletes are still high and differences between swimming, cycling and running VO2 maximums are less than those reported for single sport specialists as well as the general population (O’Toole, M. and P. Douglas, 1995).

Fractional utilization (%VO2 max) is the percentage of VO2 max that can be sustained for the duration of the endurance event (O’Toole, M. and P. Douglas, 1995). This variable is highly dependent upon the lactate threshold. When the rate of lactate appearance exceeds the rate of lactate disappearance, lactate threshold has been reached. Production of lactate at a rate above its clearance limits ATP production and decreases pH. As a result, fatigue ensues. In long competitions where work rate is maintained below the lactate threshold, lactate is used as an energy substrate. Thus, a goal for endurance performance is to work at %VO2 max in which lactate can be efficiently cleared (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5th Ed.).
Economy of motion, the amount of work required to maintain a given velocity, is dependent upon the balance of energy input and the resultant mechanical output (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5th Ed.; O’Toole, M. and P. Douglas, 1995). Triathletes increase economy through adaptations to training stimuli. The primary adaptations to endurance training are an increase in mitochondrial and capillary density, which enhance oxygen and substrate delivery. Even with training induced improvements, the mechanical efficiency of human locomotion is between 20 to 30% for running and cycling and only 5 to 9.5% for swimming. In triathlon, ergogenic aids such as wetsuits and drafting in swimming as well as drafting and bike technology (ie. aerobars) in cycling, can be utilized to improve economy.

These physiological variables, VO\(_2\) max, fractional utilization, and economy of motion are known to be well developed in well trained endurance athletes and to have high correlations with endurance performance (O’Toole, M. and P. Douglas, 1995). Nevertheless, optimal performance in each individualized sport requires a comprehensive understanding of the many facets which comprise the athlete, training and competition.

Cross Training: The Unique Feature of Triathlon

The sequential, multisport modality of triathlon distinguishes the sport of triathlon from other endurance competitions. Inherently, all triathletes cross-train. Cross
training, by definition can be: 1) the participation in an alternative training mode exclusive to the one normally used in competition, 2) combined alternative training modes with sport-specific regime; 3) cross-transfer of training effects from one sport to the other one (Millet, G. P., et al., 2002). The cross-training effect or transfer between differing modes of exercise is theorized to occur when one mode of exercise enhances central adaptations that are employed when an alternative mode of exercise is performed. Such an increase in central adaptations augments blood flow to active and inactive skeletal muscles. Higher blood perfusion permits the active musculature to do more work and contributes towards the oxidation and clearance of lactate. Cross-training is also beneficial in that it reduces the propensity for musculoskeletal injuries and burnout as well as allows athletes to engage in more high intensity training sessions in a given period of time as the specific stresses of one exercise mode will be somewhat alleviated by the specific stresses imposed by an alternate exercise form.

A cross training effect is evident between running and cycling. Cycling and running locomotion is primarily driven by the knee extensors, therefore training in either mode trains this major muscle group and creates transfer between the different exercise modes. In a study of female runners, supplementing 4 weeks of cycle training instead of running did not significantly reduce running VO$_2$ max; indicating that cycling can be substituted for running when an injury is present without significant decrements to aerobic capacity (Millet, G. P., et al. 2002). The transfer of
exercise induced adaptations is beneficial to the training of recreational individuals; however, elite athletes who striving for optimal performance in their given discipline must focus on specificity of training. Cross-training, through limitations on specificity, hinders optimization of sport-specific performance.

Specificity is a concept emphasizing the ability of the body to cope to the precise exercise stress applied with no exercise induced adaptations beyond the specific training stress. The training stimuli must induce fatigue that results in performance decrements and ensuing positive adaptations during a recovery period of high quality. Yet, in the application of specificity, the training induced adaptations are less centralized and more localized to the specific peripheral muscles worked. A specific training response will occur when specific muscle groups are utilized in an event specific way and the cardiovascular load is of insufficient demand to elicit a central adaptation.

The need for specificity of training is superior to the need for cross-training in order to reach optimal performance. Triathlon is unique in that it combines three endurance sports in series, thus, traditional cross-training is innate to triathlon, presenting a challenge to the specificity concept. In training, appropriate weight must be given to each discipline as well as to the two transitions based upon the respective contribution of each area to overall triathlon performance. To achieve optimal triathlon performance, triathletes train in multiple sessions per day or perform back to back
(brick) workouts. A well-designed training program accounts for the cross-training effect between disciplines while simultaneously emphasizing specificity of the mode being trained. Although elite triathletes may train in cycling at loads comparable to elite cyclists, triathletes have demonstrated a less efficient cycling ability as evidenced by variable neural recruitment and skeletal muscle activation. These findings in triathletes are similar to findings reported in novice cyclists (Chapman, A.R., B. Vicenzino, and P. Blanch, 2008). These findings may be resultant from motor interference which develops in triathletes who heavily train different neuromuscular firing systems, making it difficult for the body to distinguish each independent system for the most efficient level of firing in a given discipline. This hypothesis has been tested in elite triathletes and matched runners, but the results were not aligned with the previous findings. Swimming has yet to conduct a study of similar design.

Swimming

Of the three disciplines in triathlon, the swim is the most specific event. Swimming receives less transfer from the cross-training effect of cycling and running (Millet, G. P., et al. 2002). Performance in swimming, like cycling and running, depends on aerobic capacity; but unlike cycling and running, swimming is highly dependent upon technical skill (Zamparo, P., C. Capelli, and D. Pendergast, 2010).
The importance of aerobic capacity in swimming can be easily overlooked as a result of the dependence on technique and because swimming taxes the aerobic system less due to the horizontal position assumed while swimming; which lowers perfusion pressure on the capillary beds leading to a decreased heart rate, ventilatory and VO$_2$ response. Furthermore, in swimming, the arms are used for 70% of the locomotion (Faulkner, J.A., 1966). Consequently, utilization of a smaller muscle mass is less demanding on the cardiovascular system. Yet, the importance of aerobic capacity in swimming is emphasized by the high VO$_2$ max possessed by elite swimmers (Holmer, I., 1972; Fernandes, R. J., et al. 2006). Moreover, sedentary subjects undergoing 11.5 weeks of swim training increased VO$_2$ max to the same extent as their counterparts did with run training (Millet, G. P., et al. 2002). In, endurance swimming, 3K or Ironman swims typically take Long Distance Swimmers and Ironmen Triathletes 45 minutes to an hour or more. Clearly, this duration of work relies heavily upon the aerobic system for energy expenditure (Hill, D.W., 1998).

However, triathletes have been found to lack technical skill in swimming (Toussaint, H.M., 1990) and are often reported to swim slow (Lepers, R., 2008; Toussaint, H.M., 1990) relative to swimmers. These findings are well aligned with published work by Barbosa (2010) which illustrates the role of energetic as well as biomechanical parameters on swimming. Biomechanical parameters of importance are the stroke parameters; stroke frequency and stroke length; velocity of hands and feet; index of coordination and total time gap. These parameters are influential on the velocity of
swimming which ultimately affects the energy cost of swimming (Barbosa, T. M., et al. 2010).

The energy cost of locomotion has been described as the best physiological predictor of human locomotion in terrestrial and aquatic environments (di Prampero, 1986; Capelli, P., et al. 1995; Zamparo et. al 2005) as it is a measure which accounts both energetic and biomechanical factors. Energy cost (kJ/m) is derived from the ratio of net energy expenditure (kJ/min) to velocity of motion; making the measures of VO$_2$, lactate and pace are critical for energy cost determination. The units of energy cost, kilojoules per meter, indicate energy cost is a measure representative of the amount of work required to travel a unit distance. Thus, energy cost is a way to quantify the economy of swimming. An economical swimmer, therefore, is one who uses minimal energy expenditure to maintain a consistent pace over a distance (McArdle, W.D., Katch, F.I., and Katch, V.L., 2001, 5th Ed.).

Physiological testing in swimming was limited until about the 1970s due to the complexities of testing in the aquatic environment (Zamparo, P., C. Capelli, and D. Pendergast, 2010). In 1972, Holmer (1972) first utilized a swimming flume which allowed VO$_2$ testing to be conducted in a controlled pool which operated like an underwater treadmill. About a decade later, Toussaint (1983) published work on a respiratory snorkel. This device enabled oxygen consumption measures to be collected as a swimmer swam in a standard pool with technicians walking on deck.
adjacent to the swimmer ensuring air flow between the snorkel and a Douglas bag. In more recent times, Keskinen (2003) has validated the Cosmed K4 b², permitting breath by breath data through the portable analyzer set-up as the subject swims in either a flume, standard pool or open water. Yet, each of these methods of oxygen consumption measures taken during the swim obstruct the swimmer from swimming in natural form and require the expensive purchase of swimming exclusive equipment. The back extrapolation method, first used by di Prampero (1976), applied to swimming by Montpetit (1981) and later validated by Costill (1985), lets the swimmer swim freely. VO₂ measures are taken immediately upon completion of the swim and extrapolated backwards to a VO₂ at time zero which is representative of the swimming VO₂. This method is widely utilized in swimming research today (Millet, 2000; Rodriguez, 1999, 2003; Zamparo, 2000).

Swimming in Triathlon

The triathlon swim constitutes a lesser overall proportion of the overall triathlon race relative to the run and cycle. In an Ironman race, the swim is only 10% of the overall race distance whereas in Sprint triathlons, the swim makes up no more than 18% of the overall race. The current race distances of triathlon were not devised off of physiological or equally contributing proportions. Rather, the Ironman distances were implemented according to the longest races held in Hawaii for swimming, cycling and running. Similarly, the Olympic Distance triathlon was created by conjoining internationally sanctioned distances in the three triathlon sports.
Accordingly, a triathlete does not need to swim well for an overall good performance in triathlon. In fact, anecdotally, triathletes, in relation to the Ironman, have reported the competition mantra, “Do not drown in the swim, hammer it on the bike and pull off a 4 hour marathon!” Perhaps parallel, many triathletes take on the sport with a prior background in running or cycling and not swimming. Nevertheless, the swim in triathlon should not be disregarded as several studies have illustrated prior exercise reduces subsequent performance (Millet, G. P., P. Dréano, and D.J. Bentley. 2003; O’Toole, M. and P. Douglas, 1995; Sleivert, G., and H. Wenger, 1993). When fatigue sets in, economy of motion deteriorates with accompanying performance decrements such as glycogen depletion, damage to muscle fibers, and increased work of breathing and increased body temperature (Guezennec, C. Y., et al. 1996; O’Toole, M. and P. Douglas, 1995). Cycling and particularly, running in a triathlon are most affected by decreases in economy; being the latter stages of the race. Therefore, good swimming economy is important for enhanced substrate utilization and offsetting eventual performance decrements in the ensuing cycle and run.

Research on Swimmers versus Triathletes

In analyses of swimmers and triathletes, evidence suggests triathletes are inferior to swim specialists. Toussaint (1990) found increased stroke length (1.23 m vs. 0.92 m) and propelling efficiency (61 ± 6% vs. 44 ± 3%) in swimmers when compared to Olympic Distance Triathletes; yet, the study was only performed on short distance triathletes and comparable swimmers and Kreider (1988) has reported findings in
short distance triathletes are not necessarily transferrable to long distance triathletes. In an analysis of the Hawaii Ironman, Elite Ironman Triathletes finished the swim stage of the 2006 Hawaii Ironman on average 9-10% slower than Elite Long Distance Swimmers of the 2006 Waikiki Roughwater Swim race; a race of similar duration and intensity. However, comparison of swimmers and triathletes based off of race times alone is an invalid comparison as the races performed on different days introduce variable weather and water conditions. Moreover, the two groups of athletes were involved in different competitions and it is not known if the swimmers could swim faster without the ensuing cycle and run. Although, Laursen (2000) found Ironmen Triathletes who swam 3000-m did not decrease performance in subsequent cycling, this study focused measurements on the subsequent cycle without addressing measures of swim performance. Performance measures in long distance swimming are crucial as Zamparo (2005) demonstrated that fatigue was involved in the increase in energy cost and decrease in stroke length in long distance swimming by Elite Long Distance Swimmers. Yet, unlike Long Distance Swimmers, measures of swimming economy over the course of a long swim have not been shown in Ironman Triathletes (Zamparo et al., 2005).

The present study
Swimming economy in Ironman Triathletes has not been studied. It is not known if the Long Distance Triathletes are inclined to maintain initial swimming economy at the end of an Ironman swim due to the nature of triathlon competition which demands
further high energy expenditure at the completion of the swim for the ensuing cycle and run. Ironman Triathletes have not been compared with Long Distance Swimmers over the course of a long swim on the economy of swimming and the stroke parameters: stroke frequency and stroke length. Due to the inherent cross-training in triathlon and the high specificity of swimming; it is possible that Long Distance Swimmers are more economical compared with Ironman Triathletes. This study aims to address the aforementioned uncertainties. Information from this study can be used to further the understanding of the sport-specificity of long distance swimming as related to the metabolic and mechanical effects pertaining to Long Distance Swimmers and Ironman Triathletes. This knowledge is useful to researchers, coaches and athletes who look to improve the training, competition and lifestyle of Ironman Triathletes.
Chapter 3: Methods

Research Design

The design of the study is constructed to test two groups of endurance athletes who swim long distances, Ironman Triathletes and Long Distance Swimmers, but who differ in their training and competition approach. The subjects participated in a pool-based endurance swim, representative of actual competition. The subjects were assessed and compared on swimming metabolic values and stroke mechanics pre and post a long swim to test the hypothesis: 1) Long Distance Swimmers present greater swim economy before and after a long swim as demonstrated by reduced energy cost and stroke frequency and increased stroke length relative to Ironman Triathletes. 2) Ironman Triathletes are able to maintain initial swim economy at the end of a long swim to a greater degree than Long Distance Swimmers.

This study consisted of two sessions of testing per subject. The first session of 1.5 hours was a ‘Baseline and Familiarization’ session (BFS) which consisted of a body composition assessment, 365.8-m competition-pace swim and familiarization to the experimental protocol. Session two was the ‘Experimental Session’ (ES) which occurred within a three hour time block. During this session, subjects swam 3x365.8-m, 1x1829-m and 3x365.8-m. Each individual swim was considered a trial. Trials were separated by 60 seconds for measurements of recovery VO$_2$ and an immediate post-swim lactate.
Following collection of measurements, subjects immediately resumed swimming the prescribed velocity and duration of the next trial until completion of the protocol. The swim of the subject was recorded by video throughout the ES for subsequent analysis of stroke frequency and stroke length.

Subjects

A group of 14 endurance athletes were tested. Within this group, 8 were Ironman Triathletes (T) and 6 were Long Distance Swimmers (S). These subjects volunteered to participate in the study upon receiving one of the various modes of recruitment (flyer, email communication, word of mouth). Interested participants completed a Health and Training Questionnaire to verify eligibility for the study.

Inclusion Criteria

The subjects recruited were required to meet specific inclusion criteria. Subjects needed to be healthy and well-trained in their respective sport. Healthy was defined by achieving a stratification of Low Risk according to the American College of Sports Medicine risk stratification classification which stratifies individuals to low, moderate or high risk based upon review of health and medical history for known disease, signs/symptoms, and risk factors for cardiovascular, pulmonary and/or metabolic disease. All subjects were stratified Low Risk based upon age (females ≤ 55; males ≤ 44) and answers to the medical portion of the Health and Training Questionnaire. Well-trained was defined by two or more years of competition in sport and current training for a T of a
minimum of 12 hours/week and for S a minimum of 6 hours/week. However, the criteria ‘well-trained’ needed to be adjusted throughout the study to achieve a greater sample size. Consequently, for both groups, years of experience in sport was reduced from 2 to 1 year and for S, hours/week of training was reduced from 6 to 4 hours. Additionally, effort was made to ensure T swam at least two hours per week and S performed minimal cross-training.

Justification of sample size

A total of 20 subjects (10 per group) were initially proposed for this study. This number was derived by doing a test of a priori power analysis with power equal to 0.80, effect size equal to 0.82, and alpha equal to 0.05. Also, the studies that were reviewed used similar sample sizes, typically of 6-11 subjects (Chapman, A. R., Vicenzino, B., & Blanch, P., 2008; Toussaint, 1990; Zamparo et al., 2005;). 14 subjects (7 per group) are needed in this situation to see a significant effect. An additional 6 subjects (3 per group) were requested to cover any drop outs. Males and females were both recruited to help reach the desired sample size, although pregnant women were excluded due to potential adverse effects on the fetus resultant from the vigorous nature of the exercise. All females who participated received a pregnancy test (Early Result Pregnancy Test, CVS Pharmacy) during BFS and were tested during the follicular phase of the menstrual cycle to avoid the confounding effects of changes in body temperature, sweat rate, and body water that are correlated with the luteal phase of the menstrual cycle (Garcia et al., 2006).
Yet, as is typical in human subject research, this study was limited by the final number of participants. A total of 10 T, 9 males and 1 female, were tested but one male dropped out in the ES due to muscle cramping and the stroke mechanic data of the female could not be analyzed due to malfunctioning of video equipment. As a result, the final number of T subjects was 8. A total of 6 S were tested, 4 females and 2 males. All 6 S successfully completed the ES.

Protocol
Informed Consent

Eligible subjects arranged an initial appointment with key personnel at The Ohio State Physical Activity and Educational Services Building to receive an in person overview of the study which provided the subject the opportunity to address any questions and concerns regarding the study. Willing subjects agreed to participate by signing the Informed Consent. The Informed Consent was an Institutional Review Board (IRB) approved document depicting the rights of the subject throughout the course of the study. Upon signature of the Informed Consent, the initial appointment proceeded into the start of the BFS.

Baseline and Familiarization Session

Subjects arrived to the BFS, having abstained from food and vigorous exercise for 3 and 24 hours, respectively, prior to the visit. Subjects were instructed to bring a swimsuit made of Speedo or lycra material, goggles, and if preferred, a swim cap. The BFS began
by having the subjects complete an Ohio State Recreational Sports Guest Pass
Registration and Release of Claims form. Completion of this form granted the subject
access to The Ohio State McCorkle Aquatic Pavilion where the study would take place.

Body Composition

Body composition was measured using the Bod Pod (Life Measurement, Inc.). The Bod
Pod has high test-retest reliability (Noreen and Lemon, 2006). Prior to each test the Bod
Pod was calibrated according to the operator manual. The height of the subject was
obtained from a standiometer. Thoracic gas volume and bone density of each subject
were estimated based upon published prediction equations inherent to the Bod Pod
system. All tests were performed according to the Bod Pod Operator Manual. Body
composition was determined by the Bod Pod using the principles of whole body
densitometry and applied to the body composition prediction equations of Siri and
Brozek (1956).

365.8-m Competition-Pace Swim

The 365.8-m competition pace swim proceeded the body composition test. The swim
was conducted in a private lane within one of the four 22.86-m pools at the McCorkle
Aquatic Pavilion. The exact pool used for this swim depended on availability. The
available pools ranged in water temperature from 26.1 to 28.3°C. Subjects were
briefed on the pacing protocol for the ES. Individualized estimated paces were provided
for each subject based upon reported best and current racing times from the Health and
Training Questionnaire. Subjects were instructed that when swimming, excluding warm-ups, there would be no flip turns, push-offs or gliding when changing swimming direction. The subject was given 10 minutes to warm-up with a warm-up that would later be repeated for the experimental trial. Following the warm up, subjects completed the 365.8-m swim at a pace they predicted could be maintained for an Ironman or 3k Open Water Swim competition. Key personnel counted laps, timed the swim with a stopwatch (Ironman 50 Lap, Timex) and ensured subjects reversed swim direction according to protocol. The time to complete the 365.8-m swim time was used in conjunction with reported racing times to establish approximate paces for the ES.

Familiarization

Following the 365.8-m competition-pace swim, key personnel familiarized the subject to the upcoming ES. Key personnel explained the following: 1) layout of the test setting (ie. equipment involved, positioning of equipment), 2) experimental protocol (including pacing and measurements), 3) instructions for the subject (ie. breathe normally, avoid talking, limit splash, no flip turns/push-offs/gliding). Lastly, the subject was fitted for a mouthpiece and asked if they had any questions pertaining to the study.

Experimental Session

Subjects arrived for the ES within 7 days of the BFS. Subjects met a student assistant outside The Ohio State Recreation and Physical Activity Center to acquire a parking and facility pass. A student assistant escorted the subject to the McCorkle Aquatic Pavilion
Competition Pool. Subjects utilized locker rooms to change into swim gear if gear was not already on. Subjects met key personnel at pool deck of Competition Pool where subjects were instructed to sit still for 5 minutes prior to measurement of a resting lactate value. All testing in the ES occurred in a private 22.86-m end lane in the Competition Pool where water temperature is 26.1°C.

Swim Protocol

Subjects were given 10 minutes to warm-up in the private 22.86-m end lane with the warm-up that was used in the BFS. The swim protocol for the experimental trial was modeled after work published by Zamparo (2005). The protocol consisted of the following swims: 3x365.8-m, 1x1829-m, 3x365.8-m. Thus, a series of swims preceded (pre swims) the 1829-m long swim and a series of swims followed (post swims) the 1829-m long swim. Each individual swim was considered a trial. The swims were to be paced according to the following velocities: 5% slower than competition pace, competition pace, 5% faster than competition pace, competition pace, 5% slower than competition pace, competition pace, 5% faster than competition pace per trials 1 thru 7, respectively. Subjects were provided with individualized estimates for pacing based off the 365.8-m swim trial and reported best and current race times. Subjects were reminded that the pacing presented were estimates. It was most important to achieve a strategy that resembled Ironman or Open Water Swim competition pace for trials 2, 4 and 6 and swim slightly slower or slightly slower faster for trials 1 and 5 or for trials 3 and 7, respectively. Additionally, it was emphasized that maintaining pace within a given trial
was of the upmost importance. When swimming, subjects were not encouraged to increase or decrease speed. Rather, when subjects exceeded or fell below the estimated pacing protocol, overall time for the swim was accepted. A student assistant kept track of the swimmer by counting individual laps and recording 22.86-m splits for the duration of the protocol. Key personnel yelled to the subject 91.44-m splits for all trials as well as when the subject had reached their last 91.44 and 45.72-m of swimming in a given trial. Furthermore, key personnel yelled to the subject during the 1829-m swim at each completion of 365.8-m. In between trials, a 60 second time period was utilized to collect measurements.

\[ \text{VO}_2 \]

\( \text{VO}_2 \) was determined by the back extrapolation method. This method was first utilized by di Prampero (1976) with speed skaters and later applied by Montpetit (1981) to swimming. This method assesses recovery \( \text{VO}_2 \) for a \( \text{VO}_2 \) value which would be representative of the steady state value attained while swimming at a steady pace. This method is advantageous in that it allows the swimmer to swim in their natural form, unobstructed from testing apparatus.

Calibration and Initial Set-Up. \( \text{VO}_2 \) was measured via indirect calorimetry (TruOne 2400, Parvo Medics). Prior to each test, the metabolic cart was calibrated for volume and gas using standard concentrations (16% \( \text{O}_2 \), 4.01% \( \text{CO}_2 \)). The cart was positioned on the pool deck approximately 0.3-m back from the edge of the pool. Hinges innate to the cart
locked the cart in place and water resistant sheets were draped over the cart as protective means for keeping the cart dry. Environmental conditions were monitored by a student assistant throughout the ES. The same student was also responsible for flushing the cart of ambient air when a subject was swimming the last lap of a trial. VO$_2$ data was set to record breath by breath.

$VO_2$ Measurement. On the last lap for a given trial, subjects swam in towards the corner of the pool as they were instructed to do so for collection of VO$_2$. Subjects touched the end wall indicating final swim time. Immediately, subjects turned toward a student assistant who positioned the mouthpiece and one-way valve in a location most convenient for the subject to grab. Subjects were told to make their first exhale into the mouthpiece. Simultaneously, the nose of the subject was pinched sealed by the fingers of the student to ensure exhaled air would not escape. A student assistant monitored the incoming VO$_2$ values for 60-seconds, providing a 30-second, 45-second, and 55-second count to all involved in the measurements.

$VO_2$ Analysis. VO$_2$ data was graphed against recovery time using Microsoft Xcel (version 2007, Microsoft Office). The VO$_2$ selected to represent the steady state swimming VO$_2$ was determined by 3 independent key personnel visually inspecting the point which separated the fast and slow components of the VO$_2$ recovery curve. The point agreed upon by at least 2 personnel or the average point of 2 closely agreeing selections was chosen as is similarly performed in lactate threshold determination. A
graph was then generated of the VO₂ fast component against time. A linear trend line was applied to the graph and the VO₂ at time zero was taken as the VO₂ during the steady state swim.

Lactate

*Lactate Analyzer Calibration.* The Lactate Plus Lactate Meter (Nova Biomedical) was calibrated with known solutions (Lactate Plus Control Solution Level 1, Level2, Nova Biomedical) within one week of each test as suggested by the manufacturer.

*Lactate Measurement.* An initial lactate value was taken after 5 minutes of rest upon arrival to the ES. Swim lactates were obtained from a fingertip blood lactate measured immediately post swim. Key personnel immediately took hold of the nearest arm of the subject. The selected fingertip (middle, ring or pointer) was dried with a cotton towel. Next, an alcohol swap was used to clean the finger of chlorine and other impurities which could affect the lactate sample. Gauze was used to dry the finger. Key personnel squeezed the finger for a minute droplet of blood, wiped off the first droplet of blood, and took the lactate sample using the second droplet of blood.

Stroke Frequency and Stroke Length

*Video Recording.* Video of the ES swim was recorded using an underwater camera system (SV4, StrokeView). Four cameras were arranged to capture each lap of the swim in its entirety. Two cameras were positioned on deck, each 4.5-m in from both ends of
the pool. These cameras captured the stroke above water as the subject entered/exited the middle 14-m of the pool. A third camera was placed 4.5-m in from the north end of the pool and in the water looking south. This camera was carefully positioned to touch the inside underwater wall of the pool so as to avoid disrupting the subject but still enable video capturing in the sagittal plane. The fourth camera was placed at the bottom of the pool, on the south end, approximately 1.8-m in from the end of the pool. This camera captured the swimmers front side. Upon completion of the swim protocol, video recording was stopped and burned to a digital video disc (DVD, Memorex).

*Stroke Frequency and Stroke Length Analysis.* Subsequent video analysis of the swim determined stroke frequency (SF) and stroke length (SL). To reduce the limitations imposed on the study by use of the 22.68-m pool for an open-water simulated swim, SF and SL were determined by assessment of the stroke in the middle 14-m of each lap within the middle 183-m of each trial. During the 1829-m trial, the stroke was assessed in the middle 183-m of every 365.8-m interval. The time to complete 4 strokes was measured by key personnel using a stopwatch (Ironman 50 Lap, Timex) and timing the swimmer through 4 complete stroke cycles based on right hand entry. The highest and lowest times were discarded, resulting in an average of 6 times used to calculate the time taken to complete 4 strokes which was extrapolated to yield the number of strokes taken per minute or stroke frequency. Stroke length was obtained by dividing the swimmers pace by the stroke frequency (Starling et. al., 1995; Zamparo et. al, 2005).

Energy Cost Determination
Energy cost of the swim was determined by the method utilized by Zamparo (2005). Aerobic and anaerobic energy costs were summated and divided by the pace of the swim for each trial. *Calculation of aerobic energy cost:* The net VO₂ was taken as the VO₂ steady state minus resting VO₂ which is assumed to be 5 ml O₂/kg/min (Capelli et al. 1995). Relative VO₂ was converted to absolute VO₂ and multiplied by 20.9 kJ, in accordance with the assumption that 1 L of O₂ consumed in the human body yields 20.9 kJ of metabolic energy, if and only if RER equals 0.96. *Calculation of anaerobic energy cost:* The net lactate value was taken by the difference between the swimming and resting lactate measures. The energetic value of lactate was determined by the conversion factor of 0.0689 kJ/kg/mM (diPrampero, 1981) and divided by the distance traveled. Therefore, net lactate was multiplied by 0.0689 as well as the mass of the subject and divided by either 365.8-m or 1829-m, depending on the trial. Summation of both the aerobic energy expenditure, derived from net VO₂, and anaerobic energy expenditure, derived from net lactate, yielded total energy expenditure which was then divided by the pace of the swim to yield the overall energy cost of the swim.

**Biostatistical Design and Analysis**

Independent Sample T-Tests were used to determine statistical significance of variables of interest in trials 1, 2 and 3 (PRE), trial 4(LONG) and trials 5, 6 and 7 (POST) using SPSS version 17.0 statistical software. Significance was set a priori at 0.05.
Chapter 4: Results

Subjects

The data of 14 subjects was analyzed. Of these subjects, 6 were Long Distance Swimmers and 8 were Ironman Triathletes. All 8 T were males while the S group consisted of 2 and 4 males and females, respectfully. A significant difference in weight (p<0.05) existed between the groups. No statistical differences existed between age, height and body fat (p>0.05). [Table 1]

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Body Fat%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Years</td>
<td>cm</td>
<td>Kg</td>
</tr>
<tr>
<td>T</td>
<td>8</td>
<td>0</td>
<td>34.4 ± 5.9</td>
<td>176 ± 9.3</td>
<td>84.0 ± 8.7</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>4</td>
<td>30.5 ± 5.2</td>
<td>170 ± 5.9</td>
<td>64.0* ± 8.0</td>
</tr>
</tbody>
</table>

Table 1. Descriptive characteristics. Data presented as means ± SD. *A significant difference existed between T and S for weight (p<0.05).

Current training (swimming, cycling, running) in hours per week, sessions per week and kilometers per week is presented as means ± standard deviation (SD) for S and T in Table 2. T trained a significantly greater number of hours per week (13.8±2.5, p<0.05), sessions per week (10.2±1.7, p<0.05) and kilometers per week (179±64, p<0.05) compared to hours per week (6.00±1.8), sessions per week (5.50±1.8) and kilometers per week (34.5±22) for the S. At the time of testing, S had been training at their current volume on average for 42.2±60 months while T had been training at their current volume for an average of 11.6±16 months.
Table 2. Current swimming, cycling and running training. Data presented as means ± SD. *T and S differed significantly on hours per week, sessions per week and kilometers per week of training (p<0.05).

<table>
<thead>
<tr>
<th>Group</th>
<th>Hrs/Wk</th>
<th>Sessions/Wk</th>
<th>Km/Wk</th>
<th>Months at present volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>6.00 ± 1.8</td>
<td>5.50 ± 1.8</td>
<td>34.5 ± 22</td>
<td>42.2 ± 60</td>
</tr>
<tr>
<td>T</td>
<td>13.8* ± 2.5</td>
<td>10.2* ± 1.7</td>
<td>179* ± 64</td>
<td>11.6 ± 16</td>
</tr>
</tbody>
</table>

Current swimming training in hours per week, sessions per week and kilometers per week is presented as means ± SD for S and T in Table 3. T trained significantly less hours per week (3.44±0.7, p<0.05) sessions per week (3.06±0.7, p<0.05) and kilometers per week (8.23±3.4, p<0.05) when compared to hours per week (4.96±0.7), sessions per week (4.25±0.8) and kilometers per week (14.6±5.7) of the S. Table 3 presents the competitive swimming background of S and T. All S had a previous competitive swimming background (3 college, 3 high school) while T had mixed competitive swimming backgrounds (2 college, 1 high school, 5 no background).

Table 3. Current swimming training and previous competitive swimming background. Data presented as means ± SD. *The swimming training of S is significantly greater than T for hours per week, sessions per week and kilometers per week (p<0.05). C= collegiate swimming career, HS= high school swimming career, N/a=subject did not swim in college or high school.
Table 4 presents S and T training and racing backgrounds for long distance swimming and Ironman Triathlons, respectively. S have been swimming greater than 4 hours per week on average for 8.08±4.5 years and have been racing long distance swims on average for 2.60±1.5 years. On average, swimmers have completed 3K Open Water Swim competitions in 44.7±3.5 minutes. However, two S subjects have not competed in a 3K Open Water Swim. Instead, one subject completed an open water 5k (55 minutes) and the other subject completed a pool 1.5K (20 minutes). Both of these subjects were long distance swimmers in college. T have been training greater than 12 hours per week for an average of 5.40±6.0 years and have been racing Ironman distances for an average of 2.90±1.4 years. For a 3.8-Km Ironman swim, the T subjects averaged a time of 64.2±12 minutes and completed the Ironman Triathlon in an average of 12.2±1.8 hours.

<table>
<thead>
<tr>
<th>Group</th>
<th>Yrs Training</th>
<th>Yrs Racing</th>
<th>Best 3K OWS Time</th>
<th>Best IM Swim Time</th>
<th>Best IM Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>min</td>
<td></td>
<td></td>
<td>Hrs</td>
</tr>
<tr>
<td>S</td>
<td>8.08 ± 4.5</td>
<td>2.60 ± 1.5</td>
<td>44.7 ± 3.5</td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>T</td>
<td>5.44 ± 6.0</td>
<td>2.88 ± 1.4</td>
<td>N/a</td>
<td>64.2 ± 12.3</td>
<td>12.2 ± 1.8</td>
</tr>
</tbody>
</table>

**Table 4. Long Distance Swimming or Ironman Triathlon Training and racing background.** Data presented as means ± SD. S: Yrs Training= ≥4 hrs/wk swimming; Yrs Racing= ≥1 yr long distance swimming; T: Yrs Training= ≥12hrs/wk triathlon training; Yrs Racing= ≥ 1yr Ironman race. T and S were not significantly different for years of training and racing in their respective sports (p>0.05).

**Experiment**

**Time and Pace**

Time [Figure 1] and pace [Figure 2] to complete the pre and post swim trials was significantly higher and lower, respectively for T compared to S. For pre, S took an
average 5.80±0.65 min to complete the three 365.8-m swims at an average pace of 1.06 ±0.12 m/s while T were significantly slower at 6.41±0.89 min (p<0.05) when completing the three 365.8-m swims at a pace of 0.970±0.13 m/s (p<0.05). No statistical difference existed between S and T on the long swim although the S achieved a faster, but non-statistically different time of 30.3 ± 3.8 min compared to the T time of 34.0±5.3 min for paces of 1.02±0.13 m/s and 0.910±0.13 m/s for the S and T, respectively. On the post trials, S swam in a time of 6.04±0.86 min at a pace of 1.03±0.15 m/s while T were significantly slower at 6.73± 1.1min (p<0.05) at a pace of 0.930±0.14 m/s (p<0.05).

**Figure 1. Time to complete pre and post swims.** Values presented as mean ± SD. *T time was significantly higher on pre and post swims. No statistical difference existed between S and T on time during the long swim (graph not reported) (p>0.05).
Figure 2. **Pacing through swimming trials.** Values presented as mean ± SD. *T pace was significantly less than S on pre and post swims (p<0.05).

Metabolic Values

Significant differences for lactate [Figure 3] were seen for both S (p<0.05) and T (p<0.05) between the pre and post swims. For the S, lactate increased between the pre (0.250±2.5 mM) and long (3.67±2.6 mM) swims but decreased between the long and post swim (3.18±2.1 mM). The difference between pre and post lactates of the S was significant (p<0.05). For the T, lactate decreased throughout the experimental trials with a pre value of 4.64±2.4 mM, long value of 2.99±1.9 mM and post value of 2.41±1.8 mM. The difference between pre and post lactates of the T was significant (p<0.05).
Figure 3. Lactate response to swimming trials. Values presented as mean ± SD. †Lactate was significantly different on the post trial compared to the pre trial for both S and T (p<0.05).

VO\textsubscript{2} [Figure 4] was not significant amongst S and T during any trial. The trends of VO\textsubscript{2} values reveal T had lower, but non-significant VO\textsubscript{2} values for all trials. Additionally, T showed a smaller drop in VO\textsubscript{2} between the long swim trial (35.3±9.6 ml/Kg/min) and the post swim trials (34.8±8.3 ml/Kg/min) compared to the S for the long swim trial (39.6±7.3 ml/Kg/min) and the post swim trials (35.9±9.6 ml/Kg/min).
Figure 4. **VO₂ response to swimming trials.** Values presented as mean ± SD. No statistical differences were seen in VO₂ between trials for both groups (p<0.05).

Energy cost [Figure 5] was significantly lower for S compared to T in the pre (p<0.05) and post (p<0.05) trials. On the pre trial, S had an energy cost of 0.760±0.21 kJ/m while T had an energy cost of 1.02±0.22 kJ/m (p<0.05). No statistical difference was seen between groups in the long swim where the energy cost was 0.780±0.20 kJ/m and 0.960±0.21 kJ/m for S and T, respectively (p>0.05). On the post trials, S had a significantly lower energy cost value than T at 0.710±0.20 kJ/m compared to 0.960±0.21 kJ/m (p<0.05).
Figure 5. Energy cost of swimming. Values presented as mean ± SD. *Energy cost was significantly lower for S than T in the pre and post trials (p<0.05).

Stroke Mechanics

Stroke frequency [Figure 6] was not statistically different between S and T in any trial (p>0.05). S showed a non-statistically different increased stroke compared to T in all trials. Stroke length [Figure 7] was not statistically different between the S and T in any trial nor was there any significant difference in stroke length for the S in any trial. In the T, stroke length was statistically different between pre and post trials (p<0.05). S and T both displayed decreasing stroke length between the pre (S 2.07±0.28 m/str; T 1.96±0.25 m/str) and long (S 1.94±0.24 m/str; T 1.82±0.21 m/str) swim trials and maintenance of stroke length between the long and post trials (S 1.94±0.25 m/str; T 1.81±0.22 m/str).
Figure 6. Changes in stroke frequency. Data presented as means ± SD. Stroke frequency was not significantly different between S and T for any trial (p>0.05).

Figure 7. Changes in stroke length. Data presented as means ± SD. †Stroke length decreased significantly for the T between pre and post trials (p<0.05).
Chapter 4: Discussion

The findings of the study Swimming Economy in Long Distance Swimmers and Triathletes are 1) Long Distance Swimmers, compared with Ironman Triathletes, are more economical at swimming and 2) Long Distance Swimmers and Ironman Triathletes maintain economy of swimming at the end of a long swim. The first finding was mostly supported by the hypothesis while the second finding was not supported by the hypothesis. These findings and the respective interpretations are described below.

To appropriately dissect and understand the results of the present study, it is imperative to understand the underlying characteristics of the subjects tested used in this study. The small sample size and gender discrepancy will be addressed in the limitations section of this discussion. Descriptive characteristics of the swimmers and triathletes studied were similar for age, height and body fat but swimmers weighed significantly less, likely due to the greater number of females within the swimmer group. The groups were well-trained for their respective sports as years training, years racing and current training met the inclusion criteria. As expected, the overall training load of the triathletes (hrs/wk, km/wk, sessions/wk) was significantly greater than the swimmers but the swimmers exclusive training in swimming was significantly greater than the triathletes for hrs/wk, km/wk and sessions/wk. Additionally, because the swimmers all have a background of high school and/or collegiate swimming while only 3 of the triathletes swam in high
school or college, a reasonable assumption is that the stroke of the swimmers was more technically developed. The characteristics; descriptive, training and racing, for the subjects enlisted in this study are representative of age group athletes for the sports in which they participate (Bentley, D. J., et al. 2002; Capelli, P., et al. 1995). As fitness adaptations increase with training, particularly in a recreational population, it can be assumed that the triathletes in this study were more fit than the swimmers but the swimmers, according to the principle of specificity would be more proficient at swimming (Millet, G. P., et al. 2002; Palazzetti, S., I. Margaritis, and C. Y. Guezeennec. 2005).

Long Distance Swimmers, compared with Ironman Triathletes, are more economical at swimming

Long Distance Swimmers, compared with Ironman Triathletes, displayed greater swimming economy in all trials (pre, long, post) and exhibited significantly greater swimming economy in the pre and post trials. This finding supports the hypothesis that Long Distance Swimmers are more economical than Ironman Triathletes at swimming. The scientific community is in agreement that triathletes are inferior to single-sport specialists; particularly in swimming (Bentley, D. J., et al. 2002). This is a novel finding in that, to our knowledge, the swimming economy of Ironman Triathletes has not been evaluated nor has it been compared with Long Distance Swimmers.
Overall understanding of swimming economy is multi-factorial. In this study, swimming economy was quantified by units of energy cost (kJ/m) (Chatard, J.C., Lavoie, J.M., Lacour, J.R., 1990). Energy cost is derived from the ratio of net energy expenditure (kJ/min) to velocity of motion, hence, the importance of measured VO$_2$, lactate and pace (Di Prampero, P.E., 1986). The contribution of each key variable to the final value of energy cost is depicted below. Furthermore, this study assessed the biomechanics of swimming using the stroke parameters; stroke frequency and stroke length. Therefore, the comparison of Long Distance Swimmers with Ironman Triathletes is a comprehensive analysis of the bioenergetics and biomechanics of swimming.

The VO$_2$ values of swimmers and triathletes were representative of values found in Roberts (2003) study of submaximal swimming. These values are lower than those found in cycling and running due to the alterations of hemodynamic parameters in swimming resultant from the horizontal position assumed which lowers cardiac output by decreasing perfusion pressure on the capillary beds. A similar effect is also observed in supine cycling (Faulkner, J.A., 1966; Holmer, I., 1972). Furthermore, as VO$_2$ is related to muscle mass recruited, the lower oxygen consumption can also be attributed to the utilization of the arms for about 70% of the locomotion in swimming (Faulkner, J.A., 1966). In endurance events, nearly all the energy supplied comes from aerobic sources (Hill, D.W., 1998; Zamparo, P., C. Capelli, and D. Pendergast, 2010). In the present study, subjects spent an average of 70.2 minutes swimming during the entire experimental trial. Clearly, this indicates energy metabolism was primarily aerobic. The net aerobic energy expenditure of swimmers and triathletes in the present study
contributed 95% to the total energy expenditure. Thus, while VO$_2$ was a large determinant of energy cost, a lack of significance between the VO$_2$ values of swimmers and triathletes existed, lending toward the conclusion that VO$_2$ had minimal contribution in explaining the significant difference between the energy cost difference in swimmers and triathletes. Yet, swimmers displayed a trend of slightly higher VO$_2$ values than the triathletes which is an odd finding since the swimmers have a greater ratio of females to males. This can potentially be explained because the remaining male swimmers were of high caliber and therefore, swam fast with correspondingly high VO$_2$ values while the triathletes, on average, swam slower, producing on average slightly lower VO$_2$ values. No VO$_2$ max testing in the pool was performed in this study due to the low correlation of VO$_2$ max with performance (Millet, G. P., et al. 2002) and the inability to establish pacing based off of VO$_2$ max. Nevertheless, an interesting analysis would have been to compare swimmers and triathletes based upon fractional utilization of VO$_2$ max.

Lactate values in this study were similar to values reported in shorter duration swims during the pre swims and similar to values reported at the end of prolonged exercise during the long and post swims (Millet, G.P., D. Chollet, J.C. Chatard, 2000; Chatard, J.C., and B Wilson, 2008). Both groups displayed a similar trend of greater lactate values in the beginning of the swim and lesser values in the long and post trial with no significance difference between groups on any trial. Accordingly, lactate was not a contributor towards the difference in energy cost found between swimmers and triathletes, especially since anaerobic energy expenditure comprised only about 5% of total energy expenditure. Moreover, the lactate results indicate both groups efficiently
cleared lactate, an adaption associated with endurance training and the lactate threshold was not crossed by subjects in either group, as breaking this individualized point would have yielded an exponential increase in lactate. Lactate accumulation did not appear to be a function of the sport since no difference was found between swimmers and triathletes. However, large standard deviations occurred around the means for both groups in all trials; therefore, it is hypothesized according to witness of each experiment for each subject that the lactate accumulation is unrelated to training as a swimmer or a triathlete but rather is a function of the kick implemented by individual swimmers. It is known that certain swimmers are leg swimmers or arm swimmers which creates greater reliance on the legs than the arms (leg swimmer) and vice versa. Distance swimmers are more apt to be arm swimmers while sprinters are more prone to be leg swimmers (Chatard, J.C., Lavoie, J.M., Lacour, J.R., 1990). Adrian (1966) and Chatard (1990) found leg swimming to be associated with higher energy expenditure, although the increased contributions from aerobic and anaerobic sources were not reported. Intuitively, leg swimming increases the frequency of kicking which would result in greater activation of the quadriceps muscle group and consequently, more force production, ultimately leading to greater lactate accumulation. This hypothesis can be easily tested by correlating lactate accumulation to the degree of kick as measured by a biomechanical software program such as Dartfish©.

Pace is interchangeable with the variable time as it is a derivative and remains proportional to time. Thereby, only a discussion of pace will follow. The paces attained by both swimmers and triathletes were representative of recreational and low-level
swimmers as the paces swum were far lower than collegiate and elite swimmers and
triathletes used most frequently in research (Fernandes, R. J., et al. 2006; Zamparo, P., et
al. 2005). Yet, the subjects in this study performed a long distance swim in which case
pace will be invariably slower but was still much below elite long distance swimmers
(Zamparo, P., et al. 2005). Pace might have been closer to subjects used in a study done
by Laursen (2000), but there was no report of the time or pace swam by the well-trained,
non-elite subjects who undertook 3000-m of swimming followed by 3-hrs of subsequent
cycling. Pace was similar to top freestyle long distance swimmers who swam a 6-Km
open water swim in an assessment of cardiovascular parameters by Alexiou (2005). As
hypothesized, the swimmers swam significantly faster than the triathletes in the pre and
post trials and non-significantly faster in the long trial. The results were aligned with the
pacing of elite swimmers and triathletes in the Wakiki Roughwater Challenge and the
Hawaii Ironman where swimmers swam 10% faster than the triathletes while in this study
the swimmers swam 8% faster than the triathletes (Lepers, R. 2008). Swimming is a
cyclic sport with the aim of traveling a given distance as fast as possible. Thus, mean
swimming velocity can be interpreted as the best measure of swimming performance
can be attributed to the swimmers increased pace as the triathletes who also came from a
swim background swam at paces comparable to the swimmers. As pace was significantly
different between swimmers and triathletes, pace can be interpreted as an important
contributor to the significant differences observed in energy cost between swimmers and
triathletes. While pace is influential upon energy cost, pace is influenced by the biomechanical factors, namely, stroke frequency and stroke length.

The values of stroke frequency and stroke length in both swimmers and triathletes were lower than found in elite long distance swimmers (Zamparo, P., et al. 2005) but similar to competitive recreational swimmers who swam 1500-m in a study by Chatard (2008). Significant differences between swimmers and triathletes were not found for stroke frequency or stroke length. Nevertheless, trends within the data show, in accordance with the hypothesis, stroke length is higher in the swimmers than in the triathletes but, contrary to the hypothesis, stroke frequency was higher in the swimmers.

Stroke length is an index of propelling efficiency (Pendergast, D., et al. 2003; Zamparo, P., et al. 2005), the ratio of useful work to total work. An increase in stroke length has been observed in better swimmers or in situations where drag is reduced for the subject (ie. wetsuits, drafting) (Chatard, J.C., et al. 1995; Millet, G.P., D. Chollet, J.C. Chatard, 2000). The present study is aligned with work done by Toussaint (1990) which showed the stroke length and propelling efficiency of swimmers versus triathletes, respectively was 1.23 m/str and 61% versus 0.92 and 44%. In opposition of original thought, greater stroke frequency alone does not singularly indicate swimming inefficiency as higher stroke frequencies can be reflective of faster swimming speeds, according to the equation \( v=SF\times SL \) (Barbosa, T. M., et al. 2010; Zamparo, P., C. Capelli, and D. Pendergast, 2010). In swimmers, the increased stroke frequency is accompanied by concomitant increases in stroke length and pace with a reciprocal trend exhibited in triathletes. Thus, the integration of stroke frequency and stroke length by both groups of athletes represents
coordination of stroke parameters to reach the achieved pace. This finding has been observed in other studies (Alberty, Morgan, et al. 2009; Millet, G. P., et al. 2002). However, it should be noted that females, due to a lesser arm span, also exhibit increased stroke frequency which may contribute to the higher stroke frequencies found in the swimmer group.

The energy cost values of subjects in this study were much lower than those reported by Zamparo (2005; 2000) in elite long distance swimmers and in elite adolescent swimmers swimming at supramaximal speeds for obvious reasons of discrepancy in caliber and swimming protocol. Furthermore, comparable results were difficult as work done by Starling (1995) and Barbosa (2008, 2005) express energy cost in different units. The hypothesis is supported with the finding that the swimmers, compared with triathletes, have lower energy costs of swimming. Because no differences were found amongst swimmers and triathletes in VO$_2$ and lactate, it can be inferred the leading contributor to the significantly lower energy cost values in swimmers was due to the significantly faster paces achieved by the swimmers. Thus, the swimmers, relative to the triathletes, possess a greater ability to propel through the water using less energy for the speed at which they swim. Consequently and in agreement with several authors (Chatard, J.C., et al. 1995; Millet, G. P., et al. 2002; Toussaint, H.M., 1990), the swimmers are more economical at swimming and thus, are more likely to outperform the triathletes at swimming.

The lower energy cost of swimming found in the swimmers was an expected finding of the study. Aerobic capacity is a prerequisite for good swimming (Unnithan, V., et al. 2002).
2009). We know swimming develops aerobic capacity as the VO\textsubscript{2} maximums in elite swimmers are approximately 60 ml/Kg/min and 50 ml/Kg/min for males and females, respectively, (Holmer, I., 1972; Fernandes, R. J., et al. 2006), while Van Handle (1988) reported values as high as 88 ml/Kg/min and 66 ml/Kg/min in male and female world class swimmers, respectively. Moreover, in sedentary subjects, 11.5 weeks of swim training elicited similar improvements in running and swimming VO\textsubscript{2} max (Millet, G. P., et al. 2002; Seals, D.R., and J.P. Mullin. 1982). Thereby, the difference in energy cost between groups lies deeper than aerobic conditioning.

The swimmers in this study specialize in the sport of swimming, specifically long distance swimming, the discipline tested in this experiment. The principle of specificity is a foundational element of any training program where a subject seeking to gain improvement in a task-specific event must train specifically in that event (Millet, G. P., et al. 2002). Despite the triathletes training an overall greater load, the training of the triathlete is less geared towards swimming whereas the swimmers spend more time swimming as well as possess a history of swim development, warranting more optimal performance in swimming. Thus, this study like several studies (Barbosa, T. M., et al. 2010; Bentley, D. J., et al. 2002; Millet, G. P., et al. 2002) illustrates the specificity of swimming. In the practice of more swimming, especially with an understanding of technique from previous coaching, swimmers have greater opportunity to refine the skills of swimming which influence velocity; hand and foot velocity, stroke length, and stroke frequency (Barbosa, T. M., et al. 2010), ultimately, effecting and improving energy cost.
As previously stated, swimming economy, hence energy cost, is multi-factorial. There are several determinants of energy cost, discounting the proficiency of swimming alone as the sole reason for swimmers reduced energy cost relative to triathletes. In separate analyses of 101 male swimmers and 58 female swimmers, Chatard (1990, 1991) demonstrated energy cost increases with height, weight and body surface area and decreases with hydrostatic lift. Hydrostatic lift represents the tendency of the body to be more buoyant in water, an advantage in swimming as buoyancy increases horizontal position and decreases underwater torque, reducing drag which slows swimmers. Females, because of greater proportions of fat mass relative to males, are more buoyant in water, presenting improved hydrostatic lift and subsequently, improved energy cost. Males, on the other hand, because of greater body sizes, have higher energy cost. Several authors have found energy cost is greater in men than women (Chatard, J.C., Lavoie, J.M., Lacour, J.R., 1991; Costill, D. L. 1985; Pendergast, D., et al. 1977; Zamparo, P., et al. 2005) but these differences are reduced when body mass and experience are matched and eliminated in pre-pubescent years (Chatard, J.C., Lavoie, J.M., Lacour, J.R., 1991; Zamparo, P., et al. 2008) Thus, in the present study, the reduced energy cost found in the swimmers should be viewed with caution due to the greater ratio of females to males in the swimmer group and only males in the triathlete group. Additionally, energy cost increases with the square of velocity. As swimming speed increases, the hydrostatic drag the swimmer must swim against also increases, creating the increase in energy cost. A good swimming subject swimming fast can thereby present a higher energy cost than a poor swimming subject swimming slow providing the ratio of energy expenditure to
velocity is greater for the fast swimmer. But, if the comparison was made at equal velocities, the good swimmer would swim with more ease, displaying a lower energy cost. Thus, comparisons of energy cost are simpler when velocity is controlled and warrant caution, like in this study, when subjects swim at speeds relative to subjective ability.

Long Distance Swimmers and Ironman Triathletes maintain economy of swimming at end of long swim

Long Distance Swimmers and Ironman Triathletes maintained initial swimming economy at the end of a long swim. This was not an expected finding of the study as Guezennec (1996) showed an increase in energy cost at the end of a triathlon in well-trained triathletes and Zamparo (2005) found energy cost increased at the end of a long swim in elite long distance swimmers. Yet, the rational for no change in energy cost in the present study exhibited by both swimmers and triathletes can be explained by the pacing strategy adopted by the subjects and a thorough understanding of the derivates of energy cost (González-Haro, C., et al. 2005). In the final trial of a long swim, Zamparo (2005) found both male and female subjects reduced the velocity of swimming in a likely effort to offset the rising energy cost (Zamparo, P., et al. 2005). Similarly, in the present study, the pace and accordingly, aerobic energy were reduced, resulting in no change of energy cost.
Swimmers were expected to become less economical at the end of a long swim because the nature of triathlon competition demands triathletes sustain high energy outputs at the completion of the swim. However, both groups maintained energy cost through proportional, but non-significant, decreases in VO$_2$ and pace. At this rate, the subjects continue with the same energy expenditure but travel slower resulting in a greater amount of time to complete the given distance. Thus, high energy expenditure is still demanded and the risk of mechanical wear increases (Gosling, C. M., B. J. Gabbe, and A. B. Forbes. 2008; Egermann, M., et al. 2003). Therefore, maintenance of energy cost should not just be viewed as an effective pacing strategy but a response to fatigue which will make the athlete slow down until the point where completing the given distance of a competition requires an amount of work substantially higher than the velocity the athlete is able to attain, increasing the energy cost of locomotion. An unexpected finding was the significant decrease in stroke length at the end of the swim exhibited by triathletes and not the swimmers. Therefore, the swimmers showed greater maintenance of stroke mechanics than the triathletes. With the advent of fatigue, propelling efficiency decreases as seen through decreases in stroke length. So as not to compromise velocity, athletes will increase stroke frequency (Barbosa, T. M., et al. 2010; Zamparo, P., C. Capelli, and D. Pendergast, 2010). Yet, in the present study, both groups maintained stroke frequency, but compromised velocity by decreasing stroke length. Thus, the proficiency of swimmers compared with triathletes is again demonstrated through reduced deterioration of stroke mechanics. Similar findings have led researches to
recommend triathletes focus workouts on technical improvements as opposed to distance and duration.

The dilemma in triathlon racing exists for swimming subjects. In an Ironman Race, the swim constitutes just 10% of the overall race (Lepers, R., 2008). Even in shorter distance races, the swim constitutes no more than 18% of the overall race while cycling and running constitute approximately 50% and 35%, respectively (Curtis, S., G. Fellingham, and C. Reese. 2006; Delextrat, A., et al. 2003). As a result, triathletes need not possess superior swimming ability to fair well in the overall triathlon competition. Inherently, the disproportionate emphasis on swim compared with cycle and run training by triathletes is a strategy for optimal performance time. Anecdotally, triathletes have reported a racing strategy of “not drowning in the swim, hammering it on the bike and pulling off a 4 hour marathon”. Such a mantra, along with the disproportioned distances, downplays the role of swimming in triathlon. Nevertheless, the ability to complete the set distance in a manner as fast as possible is dependent upon offsetting the detrimental effects of fatigue, namely, dehydration, glycogen depletion and thermoregulation impairment (Millet, G. P., P. Dréano, and D.J. Bentley. 2003; O’Toole, M. and P. Douglas, 1995; Sleivert, G., and H. Wenger, 1993). Several studies have found significant effects of prior exercise reducing exercise capacity (Bentley, D. J., et al. 2002; Guezzennec, C. Y., et al. 1996; Hausswirth, C., et al. 1999). Although Laursen (2000) found no significant effect of a 3000-m swim on a subsequent 3 hour cycle, the swim and cycle were shorter than in an Ironman and no measurements were taken in the swim to detect the presence of fatigue.
This study is novel in that it measured Ironman Triathletes through a representative Ironman swim and found performance decrements at the end which can be attributed to fatigue and a lesser swimming ability. This may limit performance in an Ironman race and should be considered by athletes and coaches in training for an Ironman. It is also recommended triathletes take initiative to improve technical skill by emphasizing drills during swim workouts, work with a swim specific coach and have an underwater analysis of swim stroke.

Limitations
This study utilized a 22.86-m pool for the 4023-m endurance based swim which was meant to be representative of open water swim competition. Inherently, the short-course pool based swim limits the applicability of the results to the open water as well as alters bioenergetic and biomechanical parameters from what could be displayed in a longer pool or in the open water (González-Haro, C., et al. 2005). Furthermore, it was assumed that the all subjects were equally affected by the inhibition of flip-turns and push-offs. However, subjects who train with flip-turns (typically swimmers) had to make greater adjustments when turning during the ES swim than subjects who do not train with flip-turns (typically triathletes). Subjects were tested in winter and early spring. A more optimal time period to test subjects would have been in the summer to early fall when athletes are in competition mode. Finally, this study was limited by the final number of participants and in particular, the imbalanced number of males and females within each group.


Appendix A: Informed Consent
The Ohio State University Consent to Participate in Research

Study Title: Swimming Economy in Long Distance Swimmers and Triathletes
Principal Investigator: Devor, Steven T., Ph.D

- This is a consent form for research participation. It contains important information about this study and what to expect if you decide to participate. Please consider the information carefully. Feel free to discuss the study with your friends and family and to ask questions before making your decision whether or not to participate.

- Your participation is voluntary. You may refuse to participate in this study. If you decide to take part in the study, you may leave the study at any time. No matter what decision you make, there will be no penalty to you and you will not lose any of your usual benefits. Your decision will not affect your future relationship with The Ohio State University. If you are a student or employee at Ohio State, your decision will not affect your grades or employment status.

- You may or may not benefit as a result of participating in this study. Also, as explained below, your participation may result in unintended or harmful effects for you that may be minor or may be serious depending on the nature of the research.

- You will be provided with any new information that develops during the study that may affect your decision whether or not to continue to participate. If you decide to participate, you will be asked to sign this form and will receive a copy of the form. You are being asked to consider participating in this study for the reasons explained below.

1. Why is this study being done?
This study is being performed to further the understanding of swimming long distances in swimmers and triathletes who compete in events that require long distance swims. The ability to swim well requires proper development of swimming technique. Developing this technique requires an athlete to devote quality training time specifically to swimming. The multisport nature of triathlons requires a triathlete to cross-train in swimming, cycling and running which consequently, limits a triathletes ability to optimize performance in a single discipline. Evidence suggests triathletes are less skilled in a single sport when compared to athletes who specialize in one sport. Because swimming is very technique dependent, training in other endurance sports only minimally helps swimming performance.
Despite less proficiency in a given sport, triathletes may have adopted a training style which allows them to perform well in all three events in series. This study will investigate swimming economy, the amount of work required to maintain a given velocity of motion, in long distance swimmers and triathletes to see if triathletes and swimmers differ in their swimming economy at the beginning and end of a long swim and how swimming parameters (ie. stroke frequency and stroke length) correspond to changes in swimming economy between triathletes and swimmers.

2. How many people will take part in this study?

This study will recruit a total 20 subjects, 10 Long Distance Swimmers and 10 Long Distance Triathletes.

3. What will happen if I take part in this study?

Taking part in this study asks for 2 days of testing. The first session of 1.5 hours will include a body composition measurement with skin folds and BOD POD. Both methods determine body fat percent, lean weight and fat weight. Following, the subject will perform a 400-yd swim at competition pace and approximately ½ hour of familiarization with testing equipment and testing protocol. Session 2 will occur within 7 days of session one. This session is when the testing of swimming economy occurs. A total of 3200-yd will be swam. Measurements of swimming economy will occur three times before and after a 2000-yd swim. The subject will swim 3 x 400-yds, 1 x 2000-yds and 3 x 400-yds with measurements of VO2 and lactate taken immediately between sets. The subject will remain in the water between sets and breathe through a mouthpiece for the VO2 measure while simultaneously experiencing a fingertip prick for collection of a minute blood lactate sample. VO2 provides an aerobic measurement of work while lactate provides an anaerobic measurement work. Summation of aerobic and anaerobic work relative to swimming velocity is a method used to quantify swimming economy. Stroke frequency and stroke length information will be collected by video camera during the swim and analyzed post 3200-yds.

4. How long will I be in the study?

Testing for the study takes a time commitment of 4.0 to 4.5 hours. The varying time accounts for varying swimming velocity between subjects. Session 1 and session 2 are approximately 1.5 and 3 to 3.5 hours, respectively.

5. Can I stop being in the study?

You may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled. Your decision will not affect your future relationship with The Ohio State University.
6. **What risks, side effects or discomforts can I expect from being in the study?**

Minimal risk is associated with this study. Mild discomfort, obstruction to breathing and claustrophobia may be experienced due to the Specially Designed Snorkel System for VO$_2$ collection. However, these issues are easily recognizable by investigator and subject and quickly and easily correctable. A familiarization trial in session 1 will provide experience to working with the equipment and allow for necessary adjustments. Minor discomfort may be experienced with the fingertip prick during lactate measurements.

7. **What benefits can I expect from being in the study?**

Involvement in this study provides the individual with personal body composition, swimming economy and swimming parameter (stroke frequency and stroke length) information. Results from this study will advance long distance swimming and triathlon knowledge which benefits researchers, coaches and athletes in a sport where burnout and injury is prevalent.

8. **What other choices do I have if I do not take part in the study?**

You may choose not to participate without penalty or loss of benefits to which you are otherwise entitled.

9. **Will my study-related information be kept confidential?**

Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- U.S. Food and Drug Administration;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;
- The sponsor supporting the study, their agents or study monitors; and
- Your insurance company (if charges are billed to insurance).
If the study involves the use of your protected health information, you may also be asked to sign a separate Health Insurance Portability and Accountability Act (HIPAA) research authorization form.

10. What are the costs of taking part in this study?

Participants may incur a charge due to parking in one of The Ohio State University parking garages if participants are not affiliated with The Ohio State University and do not have a parking pass.

11. Will I be paid for taking part in this study?

Subjects will not receive compensation in this study.

12. What happens if I am injured because I took part in this study?

If you suffer an injury from participating in this study, you should notify the researcher or study doctor immediately, who will determine if you should obtain medical treatment at The Ohio State University Medical Center. The cost for this treatment will be billed to you or your medical or hospital insurance. The Ohio State University has no funds set aside for the payment of health care expenses for this study.

13. What are my rights if I take part in this study?

If you choose to participate in the study, you may discontinue participation at any time without penalty or loss of benefits. By signing this form, you do not give up any personal legal rights you may have as a participant in this study.

You will be provided with any new information that develops during the course of the research that may affect your decision whether or not to continue participation in the study.

You may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled.
An Institutional Review Board responsible for human subjects research at The Ohio State University reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

14. **Who can answer my questions about the study?**

For questions, concerns, or complaints about the study you may contact Michelle DiGeronimo at digeronimo.12@buckeyemail.osu.edu or (614) 292-0458.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

If you are injured as a result of participating in this study or for questions about a study-related injury, you may contact Michelle DiGeronimo at digeronimo.12@buckeyemail.osu.edu or (614) 292-0458.
Signing the consent form

I have read (or someone has read to me) this form and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction. I voluntarily agree to participate in this study.

I am not giving up any legal rights by signing this form. I will be given a copy of this form.

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Investigator/Research Staff

I have explained the research to the participant or his/her representative before requesting the signature(s) above. There are no blanks in this document. A copy of this form has been given to the participant or his/her representative.

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Witness(es) - *May be left blank if not required by the IRB*

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Appendix B: Health and Training Questionnaire
Medical Health and Swimming/Triathlon Training History

All information given is personal and confidential. All information will be destroyed if you choose not to participate or become ineligible. If you choose to participate, any identifiers will be removed and a code number will be used in their place. All information will be kept in a locked filing cabinet. This information will not be shared with anyone other than the principal investigator. This information will enable us to better understand you and your health and fitness habits. Please answer each question to the best of your ability. Should you need clarification on any of the questions below, please contact the principal investigator, Professor Steven T. Devor, Ph.D. sdevor@ehe.osu.edu or Michelle DiGeronimo at digeronimo.12@buckeyemail.osu.edu OR (614) 292-0458. Also, we will contact you if we need clarification on any items below.

Name________________________________________________
Date____________________
Address______________________________________________________________
City/State/Zip Code___________________________
Email_____________________________
Home Phone___________________________ Business Phone___________________________
Date of Birth____/____/_____ Sex________ Height_______ Weight_______
I. Signs and Symptoms
Have you ever experienced any of the following? (Please circle Yes or No)

Yes No 1. Pain, discomfort, tightness or numbness in the chest, neck, jaw or arms.
Yes No 2. Shortness of breath at rest or with mild exertion.
Yes No 3. Dizziness or fainting.
Yes No 4. Difficult, labored, or painful breathing during the day or at night.
Yes No 5. Ankle swelling.
Yes No 6. Rapid pulse or heart rate.
Yes No 7. Intermittent cramping.
Yes No 8. Known heart murmur.
Yes No 9. Unusual shortness of breath or fatigue with usual activities.
If you answered Yes to any of the above:
How often do you experience the symptom?
____________________________________

Have you ever discussed the symptom with a doctor?
____________________________________

Explain the symptom in more detail:

II. Major Risk Factors

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<td></td>
<td></td>
<td></td>
<td>2. Have you had a fasting glucose of ≥ 100 mg/dl confirmed by measurements on at least 2 separate occasions?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Has your father or brother experienced a heart attack before the age of 55? Or has your mother or sister experienced a heart attack before the age of 65?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Do you currently smoke or did you quit within the past 6 months?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. Has your doctor ever told you that you have high blood pressure?</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6. Do you have high cholesterol?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total Cholesterol:_______ HDL:_______ Date Tested:________</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Don’t Know</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7. Do you have a sedentary lifestyle (sitting most of the day in your job with no regular physical activity)?</td>
</tr>
</tbody>
</table>
III. Medical Diagnoses

Have you ever had any of the following? Circle all that apply (circle DK if you Don’t Know):

- heart attack (DK)
- angioplasty (DK)
- heart surgery (DK)
- coronary artery disease (DK)
- angina (DK)
- hypertension (DK)
- heart murmur (DK)
- liver disease (DK)
- asthma (DK)
- emphysema (DK)
- bronchitis (DK)
- stroke (DK)
- anemia (DK)
- phlebitis (DK)
- emboli (DK)
- cancer (DK)
- osteoporosis (DK)
- emotional disorders (DK)
- eating disorders (DK)
- diabetes (DK)
- thyroid disorders (DK)

Any special problems not listed above: ________________________________

If any of the above are circled, please give details and explain:

______________________________________________________________

IV. General

1. Do you have arthritis or any bone or joint problem?
   Yes  No

   If yes, please explain:
   ______________________________________________________
   ______________________________________________________

2. Are you taking any medication, vitamins or supplements?
   Yes  No

   Name them and their dosage (list both prescribed and over-the-counter medications)
   Drug name and dosage / purpose of drug / prescribed or over-the-counter
   ______________________________________________________
   ______________________________________________________
My signature certifies that all of the above is true, to the best of my knowledge.

Signature:___________________________________________Date:__________________

************************************************************************

STAFF USE ONLY
************************************************************************

Stratification: Low Risk Moderate Risk High Risk
Do meds effect BP or HR? Yes No
Comments:______________________________________________________________
Date:__________________________Initials:_______________________________
Training History

1. How many years have you been involved with endurance-type exercise? ______
2. How many years have you been Swimming? ______ Cycling? ______ Running? ______ Other? ______
3. How many months out of the year do you Train? ______ Race? ______
4. Currently, how many days per week (on average) do you spend:
   Swimming? ______ Cycling? ______ Running? ______ Other? ______
5. Currently, how many hours per week (on average) do you spend:
   Swimming? ______ Cycling? ______ Running? ______ Other? ______
6. Currently, how many miles per week (on average) do you accumulate:
   Swimming? ______ Cycling? ______ Running? ______ Other? ______
7. How long have you been training at your present weekly volume? ______

For question number 8, answer in the appropriate area:

8. a) Swimmers:
   How many years have you been swimming ≥ 6 hrs/wk, x-training ≤ 1 hr/wk? ______
   How many years have you been racing distances ≥3K? ______
   In one year, do you intend to race in a distance ≥3K? ______

b) Triathletes:
   How many years have you been triathlon training ≥12 hrs/wk, swimming ≥2 hrs/wk?
   How many years have you been racing Ironman distances? ______
   In one year, do you intend to race in an Ironman? ______

9. Were you on a high school swim team? ______
10. Were you on a college swim team? ______

11. Have you ever participated in a VO₂ exercise test before? YES NO
12. Have you ever participated in a lactate threshold test before? YES NO
13. Do you train regularly with a Heart Rate monitor? YES NO
14. Are you aware of your own stroke frequency (Strokes/min)? YES NO
15. Are you aware of your own stroke length (Yards/Stroke)? YES NO
16. Have you ever had an underwater video swim analysis?  
   YES  NO
   If yes, was it useful and how have you used the results?
   ________________________________________________________________
   ________________________________________________________________

17. Do you employ a coach?  
   YES  NO
18. Are you currently on a club or team?  
   YES  NO
   If yes, please provide name: _______________________________________

19. How much time do you allow (on average) to taper prior to an event? __________
20. How much time do you allow (on average) between competitive swim distances ≥3k
    or Ironman events? ________________________________________________
21. Do you presently do any fast interval type training? _______________________
    If so, please describe frequency, intensity, and duration of workouts
    ________________________________________________________________
    ________________________________________________________________
    ________________________________________________________________
    ________________________________________________________________

22. What do you consider to be your best racing distance? ____________________
23. What are your current competitive swimming or triathlon goals? ______________
    ________________________________________________________________
    ________________________________________________________________

24. Have you suffered any injuries in the past six months that prevented you from
    swimming/training/racing?  YES  NO
    If yes, please
    explain:________________________________________________________________
    ________________________________________________________________

25. If you have any other information that you feel is important and relevant, please
    include here
    ________________________________________________________________
    ________________________________________________________________
    ________________________________________________________________

74
Females Only

This information is necessary to plan the days of testing within the follicular phase of the menstrual cycle.

When was your last menstrual cycle? Date _____/_______

When will you begin your next menstrual cycle Date _____/_______
**SWIMMERS ONLY**
*report as much as you know and as much as is relevant to you*

**Personal Records:**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Date (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.75 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K</td>
<td></td>
<td></td>
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<tr>
<td>10 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Most Current Racing:**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Date (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-m</td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Frequency of Racing:**

<table>
<thead>
<tr>
<th>Distance</th>
<th># in the Past Year</th>
<th># in the Past 2 Years</th>
</tr>
</thead>
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<td>10 K</td>
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<td></td>
</tr>
</tbody>
</table>
**TRIATHLETES ONLY** *report as much as you know and as much as is relevant to you*

<table>
<thead>
<tr>
<th>Event (ie. Wisconsin IM)</th>
<th>Date (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ironman</td>
<td></td>
</tr>
<tr>
<td>Half-Ironman</td>
<td></td>
</tr>
<tr>
<td>Olympic</td>
<td></td>
</tr>
<tr>
<td>Sprint</td>
<td></td>
</tr>
</tbody>
</table>

### Personal Records:

<table>
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<th># in the Past 2 Years</th>
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<tr>
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<table>
<thead>
<tr>
<th>Frequency of Racing</th>
</tr>
</thead>
<tbody>
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</tr>
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