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Physiological and anthropometrical comparisons between the triathlete and the runner, cyclist and swimmer

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CHAPTER 2

LITERATURE REVIEW

Chapter 2 is a discussion of the literature concerning triathlons looking at the growth of the sport from its inception until the present day. It examines the event order and characteristics of participants, both physical and physiological. How the three disciplines impact on one another and the physical and practical limitations of each sporting code are discussed. The chapter is essentially a review of current literature surrounding the growth and development of the triathlon and its participants.

2.1 A Brief history of Triathlon

Triathlon is more than the sum of its parts. It can be defined as, "one sport, three disciplines and two transitions", (Millet, G. P. et al 2000), namely a sequential swim, swim-to-cycle transition, cycle, cycle-to-run transition and a run (Bentley, D. J. et al 2002). The triathlete trains in three modes of exercise, all of which are aerobic in nature, but each of which utilises different muscle groups to perform a variety of movement patterns (Kohrt, W. M et al 1987).

Triathlon is a unique sport because overall race performance is dictated by an athlete's capacity to excel in three sequential activities (Millet, G. P. 2004, Bentley, D.J. et al 1998). Triathlon has changed from a novel appearance to a very popular Olympic sport within the last fifteen years (Egermann, M. et al 2003).

Triathlon made its Olympic debut at the Sydney Olympics in 2000 (Landers G. J. et al 2000). Triathlon competitions are performed over markedly different distances and under a variety of technical constraints (Bentley, D. J. et al 2002).

The history of triathlon began in 1978, when the first Ironman Triathlon was held in Hawaii, USA. The triathlon originated during the awards ceremony for a Hawaii running race when a debate ensued amongst competitors about who is more fit – swimmers, runners or other athletes. One of the participants, Navy Commander John Collins, dreamt up a race to settle the argument. He proposed combining three existing races together, to be completed in succession: the Waikiki Roughwater Swim (3.8 kms), the Around-Oahu Bike Race (180 kms – originally a two-day event) and the Honolulu Marathon (42.2 kms). Fifteen men participated in the initial event that was held on February 18, 1978. Twelve completed the race, led by the first Ironman, Gordon Haller. His winning time was 11 hours, 46 minutes and 58 seconds.

In 1980, the event was filmed for the first time, by ABC's "Wide world of Sports". This brought Ironman worldwide recognition. The event drew 106 men and two women. Dave Scott, a 26 year old Masters swim coach from Davis, California, won the event in 9 hours, 24 minutes and 33 seconds. He went on to win this event six times, bringing his time down to 8:28:37.

As people became familiar with the Ironman Triathlon, other triathlons of varying distances began to take place around the world. In 1981, the race moved to Kona on the big island of Hawaii, primarily to avoid Honolulu's traffic hazards.

In February 1982, the last year that no qualifying time was needed to compete at Ironman, Julie Moss, a college student competing to gather research for her exercise physiology thesis, collapsed meters from the finish line after becoming severely fatigued and dehydrated. Despite being passed by Kathleen McCartney, Moss nevertheless crawled to the finish line, inspiring millions with her courage and determination.

The same year also witnessed the birth of Triathlon Magazine, the sports first national publication and the founding of the U.S. Triathlon series, the first national racing series.

The decade that saw phenomenal growth in triathlon, the 1980's ended with a step toward the future. In 1989 an international governing body of triathlon was formed. Twenty- five nations were represented at the founding congress of the International Triathlon Union (ITU). The focus of the ITU was to gain acceptance by the International Olympic Committee (IOC) and have triathlon accepted as part of the Olympic Program. In 1991 the IOC recognised the ITU as the sole governing body for the sport of triathlon.

In 1994 Jim Ward (age 77) became the oldest athlete ever to complete the Ironman (16hrs, 48 mins) and Dr Jon Franks became the first wheelchair competitor. In October of the same year, triathlon was named as part of the Olympic program as a medal sport at the 2000 Olympic games in Sydney, Australia.

In 1995, Darryl Haley, formerly an NFL offensive lineman, became the largest athlete at 6 ft, 5 in and 136.36 kgs, to ever complete the race. Triathlon also made its debut at the Pan American Games in Argentina in the same year.

In 1996, Zimbabwean born Paula Newby-Fraser, the first women to have broken nine hours (1992), won her eighth Hawaii Ironman and Lothar Leder of Germany became the first athlete to break the eight hour barrier at Ironman Europe.

The Ironman may be triathlon's most recognisable event, but the Olympic distance is the sport's most popular. Triathlon has evolved considerably since its inception in the late 1970's with the most significant change being the introduction of draft-legal races for the elite short distance triathlon (Millet, G. P. 2004) also called "standard", "Olympic" or classic traditional distance triathlon consisting of 1.5km swim, 40km cycle and 10km run with quick transitions from one to the other (Landers G. J. et al 2000). Drafting is allowed within the swim section of all triathlons regardless of event distance or athlete ability.

During elite short distance triathlon competitions, athletes are allowed to "draft" during the entire race, including the cycle stage. In contrast, drafting is forbidden in the cycle stage in events of lower (ie. regional) level as well as at Ironman distances (Millet, G. P. 2004, Bentley D. J. et al 2002).

The ITU distinguishes between four different distance categories: Sprint, Olympic, Medium and Ironman (Egermann, M. et al 2003).

TABLE 1: Triathlon Race Distances (km)

Event	Distance	Swim	Bike	Run
Long	Ironman	3.8	180	42
	Middle distance	2.5	80	20
Short	Triathlon*	1.5	40	10
	Sprint	0.75	20	5

* Previously known as Olympic or Classic distance

(Bentley, D. J. et al 2002)

Ironman today stands for a worldwide race schedule of long distance triathlons with its own world championships in Hawaii (Egermann, M. et al 2003). On 20 March 2005, Ironman South Africa became part of the worldwide Ironman race schedule.

In both long and short distance triathlons, competition is held between "elite" and "age-group" athletes. Elite triathletes are defined as those holding an ITU world ranking of < 125. Age group athletes compete against each other in five year age categories. Today more than 2 million participants enjoy triathlons ranging from shorter recreational distances of 30 – 40 minutes duration to the spectacular Olympic triathlon where completion times are usually in the range

of 2 – 4 hours or the gruelling Ironman ultra-endurance triathlon where completion times are usually in the range of 8 – 17 hours (Sleivert, G. G et al 1996, Hausswirth, C and Lehenaff, D. 2001, Laursen, P. B. et al 2001), with an average Ironman finish time of 13 hours (Douglas, W et al ,1987). Average completion times of elite triathletes in the Ironman distance is 8 hours 31 minutes and for the Olympic distance event, 1 hour 48 minutes and 33 seconds.

Triathlon events have distances in common with individual distance swimming, time-trial cycling and distance-running competition. Triathlons, however, are typically conducted under different environmental, tactical and technical conditions.

Unlike pool-based swimming competitions, triathlon swims usually take place in a river, a lake or the sea. They usually involve mass starts of up to 300 athletes. In contrast to the relatively uniform conditions experienced in pool-based swimming competitions, triathlons are raced under varying conditions of water salinity, turbulence and temperature. At water temperatures below 14° C (but not over 21° C) triathletes may wear wetsuits of up to 5mm thickness (Bentley D. J. et al 2002).

Triathletes are known for their ability not only to perform well in three different disciplines, but also to endure continuous physical exercise for many hours, at an optimal pace without creating fatigue that will hinder performance in the next event (O'Toole, M. L. et al 1989).

The primary determinant of success is the ability to sustain a high rate of energy expenditure for prolonged periods of time. Exercise training-induced physiological adaptations in virtually all systems of the body allow the athlete to accomplish this (O'Toole M.L. and Douglas, P. S., 1995).

Triathletes often claim a more balanced degree of fitness than a single sport athlete since different areas of the body are stressed by each of the three training activities. Typically, the cycling portion of a triathlon takes more time to complete than either of the other segments of the race. Swimming makes up the shortest portion of the race by far. The 3,8km swim portion of an ultra-endurance triathlon is completed in approximately 60 minutes by the elite ultra-endurance triathletes (approximately 10% of race time) (Dengel, D. R. et al 1989, Margaritis, I, 1996 and Laursen, P. B. and Rhodes, E. C., 2001).

2.2 Reasons for Event Order

Swimming is normally placed first for safety reasons, even though swimming after cycling or running may give the body a cooling break and a chance to rest the leg muscles. The concern is that medical problems, eg fatigue or dehydration which might occur during the swimming as a result of an earlier fatiguing run or cycle, would be much more difficult to address in the water.

Hiller, W. D. B. (1989) reported dehydration as the most common reason for a triathlete to need medical attention in an Ironman competition and hyponatraemia being the most common electrolyte disturbance in races

lasting more than eight hours (Hiller, W. D. B. et al 1986; Hiller, W. D. B. 1989). The appearance of clinical signs of dehydration and of digestive impairment may limit performance (Margaritis, I. 1996).

A more legitimate controversy is whether to run or cycle last. Proponents of the “cycle-last” theory feel that running is a more demanding event and should be performed when the competitors are still fairly fresh and well hydrated (Daniels, J.T. 1992).

Those who feel that running should be last believe it is safer to run during this time of greater fatigue because medical problems are more easily addressed than they might be if the athlete is moving along at a fast pace on a bicycle. It is also possible that the opportunity to replenish fuel and fluid during a stage of cycling (before the run) would allow the participant to enter the final stage (running) in better condition. Safety of participants must be of primary concern (Daniels J.T. 1992). From the results of all the elite and junior male and female triathletes competing at the 1997 triathlon world cup, it would appear that the most important determining factor of finishing in a place is the position of the athlete at the end of the cycle leg. At this stage, the race time is approximately 67% complete. The greatest variation in times for the male triathletes occurred in the final discipline, the 10km run leg. This could increase the probability that the winner will be a triathlete with a strong running ability and that the variation found in the run may be due to fatigue (Landers, G. J. et al 2000).

2.3 Characteristics of Triathletes

The specificity and complexity of triathlons requires training programs to be viewed as a whole, ie, a global endurance approach with specific disciplinary modes stimulating a wide variety of biomechanical and physiological responses (Sleivert, G. G. and Rowlands, D. S., 1996). This approach often generates high training volumes in order to reach a high performance level in all three disciplines. Weekly training averages of 10,5 km swimming, 304 km cycling and 72 km running in a population of experienced male and female triathletes have been reported by O'Toole, M. L. et al (1987).

Data describing both physical and physiological characteristics of elite athletes training for various single sports have often been described (Astrand, P. O. and Rodahl, K. 1986, McArdle, W. D., Katch, F. I. and Katch, V. L., 1991, Saltin, B. and Astrand, P-O, 1967). However, because triathletes compete in three sports often over ultra endurance distances their profiles may differ from more conventional athletes (O'Toole, M. L. 1987, Holly R. G. et al 1986).

The physiological demands of sequential exercise in swimming, cycling and running are unique and require the triathlete to develop physical and physiological characteristics that are a blend of those seen in endurance swimming, cycling and running specialists (Sleivert, G. G. and Rowlands, D. S. 1996). This does not imply that all successful triathletes will be the same shape and size but it indicates that an individual's physical attributes can help

predict in which discipline a triathlete is most likely to be successful or in which discipline they can improve. Similarly, triathletes with different physical attributes may excel on one type of course (eg. flat) but may not be suited to another (eg. hills), or they may excel in one discipline at the expense of the other two.

2.4 Anthropometry of Triathletes

The type of activity a person participates in can influence body build and composition. A weight training programme, gymnastics, swimming and field events in athletics would produce a different body morphology than an endurance training programme for distance running (Lohman, T.G. 1981).

Both elite and sub-elite male triathletes are similar in height to specialist cyclists, but tend to be taller than the specialist runners and shorter than specialist distance swimmers. Male triathletes are similar in weight to elite cyclists but weigh less than swimmers and more than runners (Sleivert, G. G. and Rowlands, D. S. 1996).

Elite triathletes are generally tall, of average to light weight and have low levels of body fat, a physique which provides the advantages of large leverage and an optimal power to surface area or weight ratio (Sleivert G.G and Rowlands, D. S. 1996, Laursen, P. B. et al 2001).

The body mass of elite male triathletes has been reported to range between 65 and 75 kg (Landers, G. J. et al 2000, Schabort, E. J. et al 2000). It is possible that smaller triathletes may perform better over courses involving a draft-legal undulating cycle course because of a lower gravitational force to overcome during both the cycle and running stage. In contrast, larger athletes may excel in flatter, non-drafting cycle courses. Distinguishing the most optimal physical characteristics for a particular cycling course may not necessarily result in improved overall triathlon performance (Bentley, D. J. et al 2002).

Landers G.J. et al (2000) measured seventy one elite and junior elite triathletes competing at the 1997 world triathlon championships (Olympic distance), on a battery of twenty eight anthropometric dimensions in order to determine which physical characteristics of elite level triathletes were significantly related to performance. Four distinguishable morphological factors that emerged were robustness, adiposity, segmental lengths and skeletal mass. The first factor, a robust body type, included variables of mass, girths and breadths of the trunk region as well as variables relating to mesomorphy and muscle mass. In relating these factors to the total time obtained by the triathletes it was illustrated that low levels of adiposity was important with regard to total time and in most of the sub disciplines. Total time and run times were found to be slower with increasing levels of adiposity, therefore the results from this study confirm that triathlon is another endurance sport in which adipose mass needs to be minimised. As running involves the greatest weight bearing of the three disciplines within triathlon it

was not surprising that run time was highly influenced by adiposity of the triathlete. The other factor that showed importance was that proportionally longer segmental lengths contributed to successful swimming outcome (Landers, G.J. et al 2000). The “segmental lengths” factor is important for performance prediction as these body measurements are directly related to the motor processes of stride, stroke length and frequency, where long limbs allow for greater economy of effort (Tittel, K and Wutscherk, H. 1992, Sleivert, G. G. and Rowlands, D. S. 1996, Landers, G. J. et al 2000).

Particular kinds of body size, shape and proportions may constitute important prerequisites for successful participation in many sports (Lavoie, J.M. et al 1986). Siders, W.A. et al (1993) in a study relating swimming performance (time in a competitive 100-yard swim of each swimmers major competitive stroke) to body composition and somatotype in competitive swimmers, suggest from their findings, that measurements of body composition and somatotype may be predictors of swimming performance in women but not in men (Siders, W. A et al 1993).

Among athletes, swimmers are taller and heavier than a reference population, successful distance swimmers being smaller and lighter than swimmers in shorter distances such as 100m and 200m events (Lavoie, J.M. et al 1986). In a study comparing elite open water swimmers (ultra endurance swimmers participating in events from 5km – 25km) to data collected from elite international pool swimmers at the World Championships in Perth in 1981, the open water swimmers were shorter and lighter than the pool swimmers. The

percentage muscle mass for the open water swimmers was 6,2% lower than the pool swimmers for males and 11,9% lower in females (Van Heest, J.L. et al 2004). Competitive triathletes tend to vary more in age (20 – 50 years) (O'Toole, M. L. et al 1987) and on average tend to be older than most comparable single sport athletes (Kohrt, W. M. et al 1987a; Kreider, R. B. et al 1988b; O'Toole, M. L. et al 1987).

Data from six male and three female triathletes who participated in the 1982 Ironman Triathlon showed that body fat values ranged between 5% and 11.3% for males and 7.4% and 17.2% for females. The average percentage body fat value for the four male triathletes who finished in the top fifteen was 7.1%, with a corresponding VO_{2max} of 72.0 $ml.min.kg^{-1}$ (Holly, R. G. et al 1986).

A study of triathletes training for the 1984 Hawaii Ironman concluded that the physique of both male and female triathletes is most similar to that of elite cyclists (O'Toole, M. L. et al 1987). These triathletes were found to be similar in height to single sport athletes previously studied. The weight of male triathletes tends to be less than that of swimmers but greater than that of cyclists and runners (Kreider, R. B. et al 1988, O'Toole, M. L. et al 1987). Swimmers had a higher percentage body fat than triathletes. Runners had a lower percentage body fat than triathletes (1.4% - 8% Body Fat). As a whole, male swimmers (international competitive) present a range of 5% - 10% body fat (Lavoie, J.M. et al 1986). Elite male distance runners range from 3% – 5% body fat (Noakes, T. D. 1986).

Distance runners are considerably leaner than the average population of similar age by 6 – 8 percentage points for males and females alike (Wilmore, J. et al 1977).

Body fat percentages of triathletes most closely resemble those of cyclists. (Kreider, R. B. et al 1988;) The percentage body fat of male triathletes was very similar to that of national team cyclists studied by Burke. The cyclists being 8.8% body fat and the triathletes 9.9% body fat (Burke, E. R. 1980). In a study comparing the cycling performance of highly trained competitive cyclists and triathletes, no significant difference was found between the two groups in any of the anthropometrical variables measured, namely; height, mass and the sum of five skinfolds (Laursen, P. B. et al 2003).

A better perspective on the importance of body fat to endurance athletes can be observed by comparing these percentages to those of healthy, but sedentary individuals in the general population, whose average body fat is about 15% - 16% for males (McArdle, W. D., Katch, F. I. and Katch, V. L. 1981, Lohman, T.G. 1982).

In a study comparing body composition and somatotypes of trained female triathletes to Olympic swimmers and runners it was concluded that these triathletes were closer with respect to both body composition and somatotype of swimmers than to runners. These triathletes were generally heavier, less lean, more mesomorphic and less ectomorphic than elite runners (Leake C.N. and Carter, J. E. L. 1991).

In sports where extra body fat may hinder performance, Lohman (1982) suggested a range of 4 – 10% body fat for males as an optimal percentage body fat for performance, without regard to a specific sport. Such percentages may be less critical for sports such as swimming. The buoyancy advantages that fat can offer in the swim phase of a triathlon may be largely offset by the use of a wetsuit, thereby eliminating the possible advantage that fatter individuals may have while swimming (Sleivert, G. G. and Rowlands, D. S. 1996).

In describing the appropriate physical and physiological condition for male Olympic athletes, Novak, L.P. et al 1978 recommend a total body fat content preferably below 10%, accompanied by a high lean body mass, supporting a high aerobic capacity (> 70ml.min.kg^{-1}) and supported by the respective technical skills.

2.5 Somatotypes of Athletes

A somatotype is used to assess body shape and composition independent of size, to describe populations and to demonstrate similarities and differences in groups. The relationship between success in athletics and somatotype is of particular interest. Success in athletics is a combination of genetic endowment, environmental conditions, psychological desire and condition and specialised training. Somatotype is probably one of the factors that predispose the individual to potentially high achievement.

Generally, athletes have been found to have somatotypes that distinguish them from non-athletes, from each other according to the type of sport, type of position within a sport and from each other based on achievement level (Carter, J. E. L. 1970, Liu, N.Y 1989). Berg K et al (1998) in relating somatotype and physical characteristics to distance running performance report that their main findings were that somatotype and body mass index are significant contributors to variance in running a 10km road race. The somatotype component ratings of endomorphy and ectomorphy were significantly related to 10km run time in men and women, heterogenous in ability. They recommend considering the assessment of somatotype as an independent variable in addition to physiological variables when researching the possible sources of variation in running performance as well as in the recruitment of athletes for events in which they are most likely to experience success (Berg, K et al 1998).

Carter (1970) has also shown that athletes tend to cluster in a particular area of the somatochart as opposed to being widely dispersed. A difference of 0,5 units in somatotype rating is considered to be of practical significance (Bailey, D. A. et al, 1982).

Traditionally, male distance runners have had a fairly characteristic somatotype namely ectomesomorphic with moderately high readings in both ectomorphy and mesomorphy, and since somatotype is thought to change very little with age, indicating a probable genetic link, there must be a genetic component to successful distance running (Wilmore, J et al, 1977).

The somatotype of the distance runner is characterised by high ectomorphy, medium mesomorphy and low endomorphy (Berg, K et al 1998).

Although all runners are uniformly low in the first component (endomorphy), the 800m – 1500m runners are half a unit higher on mesomorphy than the 5000m – 10000m runners and marathon runners, while the 5000m – 10000m runners are half a unit higher on the third component (ectomorphy) than the other two groups. In a review of the somatotypes of athletes, the lowest levels of endomorphy were found in distance runners and the highest level in channel swimmers. Almost all groups of championship athletes are rated high on mesomorphy but the least mesomorphic among the athletes are distance runners. Ectomorphy shows the greatest variability within most sports with distance runners having the highest rating (Carter, J. E. L. 1970).

The physique of channel swimmers is generally much fatter and less linear than those of competitive swimmers. In addition, channel swimmers are considerably shorter and heavier than competitive swimmers (Carter, J.E.L. 1970).

2.6 Aerobic Capacity

The maximum aerobic power provides a quantitative statement of an individual's capacity for aerobic energy transfer. It is also commonly known as maximal oxygen consumption, maximal oxygen uptake or simply $VO_{2max.}$

As such, it is one of the more important factors that determines ones ability to sustain high intensity exercise for longer than four to five minutes (McArdle, W. D., Katch, F. I. and Katch, V. L. 1981). Oxygen delivery to the muscles is essential in maintaining a high rate of aerobic energy production (Costill, D.L. et al 1992). Maximal oxygen uptake and physical performance are the products of natural endowment on the one side and of environmental factors and training on the other. (Holmér, I and Astrand, P-O, 1972). $VO_{2\ max}$ represents the potential of the triathlete, while economy of motion and fractional utilisation of maximal capacity represent how close an athlete can come to fulfilling his/her potential (O'Toole, M. L. et al 1995).

Studies have revealed that on average, world class athletes that compete in endurance events possess a work capacity which is about 75% higher compared with the sedentary population (Novak, L. P. et al 1978).

There is little doubt that i) a high (> 70ml.min.kg^{-1}) maximal oxygen uptake ii) the percentage VO_{2max} corresponding to lactate or ventilation threshold iii) the energy cost of exercise, contribute to successful endurance performance in running, cycling and triathlon events (Millet, G. P. et al 2004). An athlete with a high VO_{2max} has the advantage of being better able to tolerate bouts of forced tempo than the competitor with a lower VO_{2max} in that the athlete does not have to utilise the anaerobic energy yield to the same extent during bouts of increased tempo (Astrand, P. O. and Rodahl, K. 1986).

Although it constitutes an important physiological factor, $VO_{2\ max}$ is only one of the parameters explaining successful performance in prolonged exercise and cannot entirely account for the observed variations in performance. Other factors which are considered in explaining how high performance may be achieved with a relatively low VO_{2max} include the capacity to use a high percentage of VO_{2max} over extended periods of time (Di Prampero, P E. 1986), as well as the ability to minimise energy expenditure as a given intensity at sub-maximal workloads (Conley, D et al 1980, Morgan, D. W. et al 1991).

A minimal level of oxygen uptake is required but it does not always determine the performance of triathletes (Margaritis, I 1996). Although elite cyclists are also categorised by high VO_{2max} values, actual performance is influenced by extrinsic factors such as the quality of the bicycle, wind speed, air resistance and rolling resistance (Kohrt, W.M. et al 1986). Nevertheless, cycling performance in Kohrt's study, was significantly related to cycling VO_{2max} ($r = -0,78$). Coyle, E.F. et al (1988) indicate from their results on the determinants of endurance in well-trained cyclists, that individuals with a similar VO_{2max} can vary greatly in glycogen utilisation and time to fatigue when cycling at the same work rate and percentage of VO2max. (Coyle, E.F. et al 1988). Swimming performance was not however significantly related to swimming VO_{2max} ($r = -0,50$) therefore stroke mechanics and efficiency are presumably a more important determinant of swimming performance than $VO_{2max.}$ Typically, middle distance swimming is a function of both aerobic capacity and exercise efficiency (Costill D.L. et al 1985).

An interesting observation is that a swimmers heart rate may drop by five to eight beats/min when immersed in water. Consequently at a given exercise effort (ie oxygen uptake) in water, one's heart rate may be ten to twelve beats/min lower than during exercise on land. Water tends to facilitate the return of blood to the heart thereby reducing the work of the cardiovascular system (Costill, D.L. et al 1992). This may, in part, explain why swimmers will achieve a higher VO_{2max} value during running or cycling than while in water.

The primary determinant of success in triathlon, is the ability to sustain a high rate of energy expenditure for prolonged periods of time. Exercise training-induced physiological adaptations in virtually all systems of the body allow the triathlete to accomplish this. Aerobic capacity (VO_{2max}), economy of motion (sub-maximal VO_2) and fractional utilisation of maximal capacity (%VO_{2max}) reflect the integrated responses of these physiological adaptations (O'Toole, M. L. and Douglas, P. S. 1995, Sleivert, G. G. and Rowlands, D. S. 1996).
Many studies have reported relatively high mean VO_{2max} values for triathletes. In their characterisation of triathletes, Holly, R. G. et al (1986) found that the top finishers have a higher VO_{2max} and spend more time training in all events than do slower performers. This is certainly not unlike what holds true for competitors in many endurance events.

It is unusual for an athlete to be world class in more than one sport yet the triathletes studied by O'Toole, M. L. et al in 1987 have maximal aerobic capacities which are competitive with those of elite swimmers, cyclists and runners. VO_{2max} of triathletes have been reported to range from 39 – 49

ml.min.kg^{-1} during tethered swimming (O'Toole, M. L. et al 1987), 57 – 61 ml.min.kg^{-1} during cycle ergometry (O'Toole, M. L. et al 1989, Noakes, T. D. et al 1985, O'Toole, M. L. et al 1987) and 61 – 85 ml.min.kg^{-1} during treadmill running (Noakes, T. D. et al 1985, Holly, R. G. et al 1986, O'Toole, M. L. et al 1987).

Highly trained male and female swimmers have been reported to have VO_{2max} values ranging from 50 – 75ml.min.kg^{-1} and 45 – 65 ml.min.kg^{-1}, respectively. Normal active 18 – 22 year old college students have been reported to have VO_{2max} values of 44 – 50 m.min.kg^{-1} for males and 35 – 42 ml/min.kg^{-1} for females (Costill, D.L. et al 1992). The open water swimmers in the Van Heest, J. C. et al 2004 study, had a mean VO_2 peak of 5,51$\pm$ 0,096 l.min^{-1} for males. Data was converted to a relative value so as to compare this data to that of dry land athletes.

Mean values of VO_{2max} for 23 world-class male competitive cyclists in the US national team (1980) were reported to be 74,0 $\pm$ 8,3 mlO_2.min.kg^{-1}. (Burke, E. R. 1980).

The maximal aerobic power of triathletes compares favourably with maximal aerobic power commonly found in the literature for athletes who specialise in the individual sports of running, cycling and swimming and is clearly above those of untrained individuals (O'Toole, M. L. and Douglas, P. S. 1995).

Sleivert, G. G. and Rowlands, D. S. (1996) reported that although triathletes have high VO_{2max} values, they may on average be marginally lower than values previously observed in endurance specialists. Elite triathletes have significantly higher VO_{2max} values than sub elite triathletes and high VO_{2max} values are required for success in triathlons. The ability of the triathlete to exercise at a lower percentage of VO_{2max} for a given submaximal workload may be very important to triathlon success. It is however influenced not only by VO_{2max} itself, but also by anaerobic threshold as indicated by either ventilatory threshold or lactate threshold, as well as economy of movement (Sleivert, G. G. and Rowlands, D. S. 1996).

VO_{2max} values of eight male triathletes training for the 1984 Ironman were equal to or greater than those of swimmers and somewhat less than what is typical of elite cyclists and runners (O'Toole, M. L. et al 1987).

Since the triathletes studied trained less in any one sport than elite single sport athletes, the achievement of competitive VO_{2max} values suggest a true cross-training effect (O'Toole, M. L. et al 1987). Data from O'Toole's study (1987) suggests that perhaps there is some critical level below which a triathlete will not be successful, but above which other factors play a more important role in performance. (Schneider, D. A. et al 1991, Sleivert, G. G. and Rowlands, D. S. 1996). The minimum values for VO_{2max} necessary for successful performance in a triathlon have been suggested to be approximately 65 $ml.min.kg^{-1}$ and 60 $ml.min.kg^{-1}$ for elite male and female triathletes respectively (Bunc V, et al 1996).

In all endurance sports, high performance is associated with the ability to sustain work rates at a high percentage of VO_{2max}. Two factors that are associated with the ability to perform sustained cycling at a high percentage of VO_{2max} are the number of years a cyclist has competed and a high percentage of Type I muscle fibres (quadriceps) (Coyle, E.F. et al 1988).

VO_{2max} values of triathletes have been compared both with overall finish times and with performance times of each leg of the triathlon. Neither treadmill VO_{2max} nor cycle ergometer VO_{2max} correlated very well with finish times in the Hawaii Ironman Triathlon. However, Kohrt, W. M. et al (1987) reported that running and cycling times, but not swimming times were significantly related to corresponding VO2max values. In short distance triathlons and in studies using recreational rather than elite triathletes, VO_{2max} is related to performance in the corresponding event of triathlon (Kohrt, W. M. et al 1987). However, beyond typical endurance events ie, events lasting longer than 4 hours, such as the ultra endurance triathlon known as the Ironman Triathlon (3.8km swim, 180 km cycle and 42km run), performance becomes harder to predict, perhaps because of other factors encountered such as hydration and energy homeostasis (Laursen, P.B. et al 2001). While the development of high levels of aerobic power are of importance to success in triathlon racing, other physiological variables contribute much to actual race performance.

Unlike running and cycling, where the VO_2 at a given power output may be measured with good accuracy, the oxygen cost of swimming against a given resistance varied markedly among swimmers (Kohrt, W. M. et al 1989).

It is therefore suspected that efficiency is a more important determinant of swimming performance than VO_{2max}. In triathlon, economy of swimming is dependent on swimming technique and is not affected by previous exercise as this is usually the first event (O' Toole, M. L. and Douglas, P. S. 1995).

Successful triathletes must be able to perform optimally in spite of often adverse extrinsic factors that can affect cardiovascular, haemodynamic and thermoregulatory responses to prolonged exercise. (Coyle, E. F. et al 1992, Hiller, W. D. B. 1989, Laird, R. H. 1989, Speedy, N. B. et al 1999, O'Toole, M. L. et al, 1987 and 1989). VO_{2max} has been shown to be a good predictor of endurance running performance when subjects are heterogenous in terms of VO_{2max}. (Kohrt, W. M. et al 1987, Costill, D.L. et al 1973). However, in this 1987 study, Kohrt et al found bike time during a long course triathlon was related to cycle VO_{2max}. They however observed a lower correlation between VO_{2max} and performance during the run and suspect it was due to additional factors that influence running performance in a triathlon. They postulated these factors in particular included the "bike-run" transition time and fatigue resulting from the swim and cycle stages prior to the run.

In both cycling and running, exercise economy may be affected, not only by skill level of the participant, but also by previous stages of the race. It has been suggested that the awkwardness experienced immediately following a transition may not entirely dissipate (O'Toole, M. L. and Douglas, D. S. 1995). Kreider, R B. et al, (1988) reported that triathletes significantly decreased cycling work output after swimming and triathlon running, while performed at

the same work output, caused significant increases in VO_2 indicating a decreased running economy as compared with cycling and running under control conditions (no previous exercise).

The effect of cycling on running performance

Laboratory data indicate that triathlon running is harder than control running at the same speed. Oxygen consumption (VO_2), respiratory frequency, ventilation rate and heart rate are increased (Millet, G. P and Vleck, V. E.2000). It has been shown that cycling and running speed during a triathlon will be slower compared with individual performances as a consequence of the previous exercise (De Vito, G. et al 1995).

It has also been shown that the running pattern after an exhaustive cycling exercise is modified due to mechanical and sensorial alterations causing a higher energy cost of running as compared to running without prior physical activity (Millet, G.P. and Bentley, D.J. 2004). The seriousness and the duration of the alterations of running mechanics after an exhaustive cycling bout are different between elite and middle level triathletes, with the middle level triathletes showing a larger increase in their mechanical cost of running than the elite triathletes. This difference did not exist any more at the sixth minute, suggesting that the mechanical alteration due to a specific cycling fatigue is brief (Millet, G. P. 2004, Millet, G. Y. et al 2001).

The effect of swimming on cycling performance

Prolonged swimming requires the use of predominantly the upper body muscle groups. This results in blood pooling in the upper extremities (Finlay, J. B. et al 1995). The swimming stage of a triathlon has also been shown to cause a higher blood lactate concentration relative to the following cycling and running stages (Farber, H. W. et al 1991). This, combined with excessive blood pooling in the upper extremities at the end of the swim stage may affect performance during the following cycling stage. Gollnick, P. D. et al (1972) demonstrated that the patterns of enzyme activities in arm and leg muscles of swimmers were clearly different to those of cyclists. Although musculature used for cycling overlaps with that used during running, biomechanical analysis suggests that ranges of motion, lengths of muscles, type of contraction (concentric versus eccentric) and speed of contraction can be quite different. Overall cycling performance after swimming in a triathlon is not typically affected (Kreider, R. B. et al 1988, Laursen, P. B. et al 2000).

Data from Kreider et al (1988) indicate that cycling economy, ie, VO_2 relative to power output was not affected by prior swimming. Laursen, P. B. et al (2000) reported no significant differences in the average power output sustained over a three hour cycle time trial that followed a 3000m swim, however, it is possible that during the initial stages of the cycling leg, the ability of the athlete to generate the high power outputs necessary for tactical position changes may be impeded (Laursen, P. B. et al 2000).

The physical resistance opposing motion of the bicycle

The resistance to cycling comes from several sources and includes contributions from tyre/road interactions (rolling), air/body/bicycle interactions (air) and the effect of gravity on the cyclist (gravitational). From the perspective of the working muscles, the only resistance that must be overcome is that opposing rotation of the pedals (Ryschorn, T. W. 1994, Di Prampero, P. E. 1979).

A cyclist must expend energy to overcome both rolling resistance, due to energy losses as the wheels roll along the road, and air resistance (drag) with the latter increasing as the square of speed. Since cycling occurs at considerably greater speeds than does running, air resistance is the more dominant factor a cyclist must overcome (Swain, D. P. et al 1987, Di Prampero, P. E. 1979). The rolling resistance depends substantially on the inflation pressure of the tyres and on the characteristics of the road surface and the tyres. The wheel resists rolling in proportion to how much of its surface is in contact with the road. A narrow tyre inflated to a high pressure has very little of its surface in contact with the road and therefore rolls with little resistance. It is proportional to the overall weight (cyclist + bike) and is constant, independent of the speed.

The increased mass of a cyclist has four important effects: it increases rolling resistance, it decreases hill-climbing speed, it retards acceleration and it increases downhill speed (Noakes, T. D. 1989). It has been suggested that

during time trials, larger cyclists are usually more successful compared with smaller cyclists because in flat terrain competitions, the only force inhibiting forward motion is that of air resistance (Lucia, A. 2000). In cycle races where a greater portion of the race is composed of hills, smaller cyclists are more successful because they have a lower body mass and therefore less resistance to gravitational force. Lucia, A. et al (2000) recently reported that in well-trained cyclists, the body mass is significantly lower in specialist climbers, compared with flat terrain specialists (60 – 65 kg versus 70 – 75 kg). The air resistance is a function of the area projected on the frontal plane, the air density and air velocity (Di Prampero, P.E. et al 1979).

Air density is mostly affected by altitude but also by temperature and humidity. Frontal area (body size) can be reduced by adopting a suitable posture on the bike known as the “hill descent” position (Faria, I. E. 1984). Air drag can be reduced in direct proportion to frontal area.

Cycle velocity is clearly a major component of air drag. Air drag increases in relation to the square of the velocity ie, by a cyclist doubling his speed, the air drag will increase fourfold.

Friction between the surfaces of the components on the bike can dissipate roughly 5% - 15% of a cyclist’s energy, therefore good components and maintenance are essential in reducing friction.

Cycling cadence

Cadence has also been shown to affect efficiency. Laboratory tests have shown that the most efficient cycling cadence for most riders lies between 70 and 100 revolutions per minute (rpm). Above 100 rpm there is a measurable loss of efficiency. Optimal cadence (the cadence at which a cyclist is most efficient) depends partly on muscle fibre composition, but also on the speed at which a cyclist is trained to ride and in competitive cyclists it was found to range between 60 – 91 rpm (Coast, J. R. et al 1986, Ryshon, T. W. et al 1991). At higher cadences it is the fast twitch (FT) muscle fibres which are most active and therefore cyclists who are endowed with a high proportion of FT fibres will most likely choose higher cadences (Noakes, T. D. 1989). Pedalling cadence has been shown to be higher in a drafting situation where the exercise intensity is reduced compared with cycling alone ($\pm$ 90 vs 100 rpm) (Hausswirth, C. et al 1999).

It has been shown that during sub-maximal exercise the pedalling cadence of triathletes has been reduced to 83 rpm, whereas elite cyclists are able to maintain close to 90 rpm for several hours (Brisswalter, J. et al 2000, Lucia, A. et al 2001). Cyclists with high percentages of ST fibres in their Vastus Lateralis muscle demonstrate greater energy economy when using relatively lower cadence (60 vs 100 rpm) at a given percentage of VO_{2max} (Suzuki, Y. 1979).

Efficient riding therefore demands not only techniques that conserve energy, but a good fit on a fine-tuned bike. An incorrect saddle height and crank length might cause the expenditure of unnecessary effort (Faria, I. E. 1984, Noakes, T. D. 1989).

Improvements have been made aerodynamically by more streamlined construction, by the use of racing suits and streamlined helmets to reduce drag (Astrand, P-0 and Rodahl, K. 1986). There appears to be a significant advantage in mechanical efficiency in employing a higher pedalling rate at high power output (Faria, I. E. 1984).

The use of aerobars in cycling, as commonly used by triathletes, provides significant energy saving over the traditional "brakehood" cycling posture (Sheel, A.W et al 1996). Using aerobars helps the cyclist maintain the hill-descent positon when cycling on the flat (Stegmann, J. 1989).

2.7 Economy of Movement

Economy of movement is defined as the relative metabolic power or energy required to perform a given task. The task might be, for example, to swim at a velocity of $100m.min^{-1}$ or running at $300m.min^{-1}$ etc. Metabolic power or the energy cost of locomotion requirements are usually measured via oxygen intake per distance unit (expressed in $mlO_2.kg.km^{-1}$). The idea here is that the less energy it takes to perform the task, the more economical the movement is. Factors that have been shown to influence the economy of movement can be divided into two principle categories; namely extrinsic and intrinsic.

Extrinsic factors include the effect of environment, surfaces and equipment. Intrinsic factors include biological rhythms, kinanthropometry and psychological and biomechanical variables. Kinanthropometric variables include body mass, leg length and the distribution of body weight. An example could be the foot size of a runner. Extreme departures from the normal foot size at a given height could bring advantages or disadvantages to the endurance athlete (Frederick, E. C. 1992). At a given swimming, cycling or running speed, the athlete with the greatest economy of motion, consumes the smallest amount of oxygen. Therefore, any adjustments in training that improves economy can directly translate into improved performance. Energy output must be sustained for long periods of time in triathlon, therefore economy of motion is potentially very important for a triathlete. Triathlon racing demands that the triathlete develop skilled, economical movement patterns in three sports (O' Toole, M. L. and Douglas, P. S. 1995).

Studies have shown that there is very little difference in the measured values for energy expenditure per metre in elite runners (Margaria, R. P. et al 1975) indicating the influence of running technique on energy expenditure to be small (Astrand, P-O and Rodahl, K, 1986).

Running against the wind has been found to greatly increase energy expenditure. The energy cost of overcoming air resistance on a calm day outdoors has been calculated by Davies, C. T. M. (1980) to be about 2% for marathon running ($5 m.s^{-1}$) and about 8% for sprinting ($10 m.s^{-1}$). Oxygen uptake has also been shown to depend on stride length. In general, the stride

length that is natural for the individual is also the most economical one. The energy cost of running is greatly increased with an increase in stride length.

In cycling, good technique is mainly about being efficient. An efficient rider channels his effort into driving the bicycle forward and gets further and faster and with less effort than a rider who allows energy to be dissipated unproductively.

The aim of an efficient cyclist is to conserve the momentum that is largely generated by the cyclist leg-power, to interrupt it as little as possible and to use it to the best advantage. Factors that could potentially contribute to cycling economy are seat position, crank length, wheel size, body position, aerobars and shoe / pedal interfaces (Gregor, R. J. et al 1994).

Many terms are used as the equivalent of running economy such as oxygen cost, metabolic cost, energy cost of running and oxygen consumption. These expressions may be defined by the rate of oxygen uptake (VO_2) at a steady state (ie between 60% and 90% of VO_{2max}) at a sub-maximal running speed (Hausswirth, C. et al 2001). Running economy has been shown to account for a large and significant proportion of variation in distance running performance among runners roughly comparable in VO_{2max} (Morgan, D.W. 1989).

It has frequently been recognised that individuals with a similar VO_{2max} can differ in performance velocity (Londeree, B.R. 1986, Conley, D. L. and

Krahenbuhl, G. S. 1980). In general it has been shown that the best athletes are usually the most efficient. Conley, D. L. et al (1980) concluded that a high VO_{2max} (> $67ml O_2.kg.min^{-1}$) helped each athlete gain entrance to an elite performance group, but within this selected group, running economy and not VO_{2max} was the factor determining success in a 10km race (Conley, D. L. et al, 1980, Noakes, T. D. 1987). Conley, D. L. et al (1980) has also reported that highly trained distance runners have better running economies than runners of lesser ability.

Endurance events such as triathlon (or marathon running) are known to modify biological constants of athletes and should have an influence on their running efficiency. The energy cost of running appears to contribute to the variation found in distance running performance among runners of homogenous level. The decrease in running economy during a triathlon could be largely linked to physiological factors such as the enhancement of core temperature and a lack of fluid balance. The increase in circulating free fatty acids and glycerol at the end of these long exercise durations bare witness to the decrease in the values for energy cost of running. The combination of these factors alters the energy cost during exercise and hence could modify the athlete's performance in triathlons (Hausswirth, C. and Lehenaff, D. 2001).

Dengel, P R. et al (1989) suggest that economy of effort is an important determinant of performance in triathlon. Some evidence suggests that competitive single sport swimmers have better movement economy than

triathletes (O' Toole, M. L. et al 1995, Toussaint, H. M. 1990). The energy cost during the front crawl of pure swimmers is 21% – 29% lower, and propelling efficiency (the power used to overcome drag / total power output) 36,4% higher when compared with triathletes (Chatard, J. C. et al 1995, Toussaint, H. M. 1990). The result was a difference in swim velocity (1,17m.s^{-1} for swimmers vs 0.95m.s^{-1} for triathletes). Stroke rate is similar but distance per stroke is better in pure swimmers at the same relative velocity reflecting greater efficiency (Toussaint, H. M. 1990, O'Toole, M. L. et al 1995).

Economy of movement in swimming, cycling and running is related to triathlon performance and swimming economy in particular appears to be an area where triathletes could make large improvements (Sleivert, G.G et al 1996).

In a study comparing the oxygen requirements of trained competitive male and female swimmers with a group of highly trained triathletes, it was interesting to note that although many of these triathletes had aerobic capacities that were markedly higher than the competitive swimmers, very few triathletes could perform as well as even the weakest of the competitive swimmers. Although the triathletes did daily swim training, none had a prior background in competitive swimming. Therefore it appears that swimming performance is limited more by skill or technique and efficiency rather than by VO_{2max} alone. Such information may suggest that training time and effort spent on the mechanical aspects (technique) of swimming may be equally, if not more important, than time spent on improving strength and endurance (Costill, D.L. 1992, Toussaint, H. M. 1990).

The ability to perform any exercise skilfully results in a reduced demand for energy. The energy that is expended during swimming is used in part to pay the cost to maintain the body on the surface of the water and to generate the force required to overcome the resistance of the water to motion (this resistance of the water to motion is known as drag). Although the energy needed for swimming is dependent on body size and buoyancy, the major determinant of economy is the effective application of force against the water (Costill, D.L. et al 1992).

Further support for the beneficial effects of improving swimming effects comes from the effects of wearing a triathlon wetsuit on drag (O'Toole, M. L. et al 1995). Studies have shown that triathletes who wear wetsuits have better flotation and improved performance times during the swim portions of triathlons, compared with triathletes who compete without wetsuits. One interpretation is that a wetsuit may act like a layer of subcutaneous fat, retarding sinking and diminishing drag (friction). Studies have shown that wearing a wetsuit during the swim portion of triathlons can improve performance by about 7% because a wetsuit can reduce drag on a swimmer's body when swimming velocity is between 1,1 and 1,5 $m.s^{-1}$ (Bentley, D. J. et al 2002).

Toussaint, H. M. (1990) reported a 14% reduction in drag at a swimming velocity of 1.25 $m.s^{-1}$ that is a typical swimming speed over triathlon distances. At 1,50 m/s^{-1} a reduction in drag of 12% was observed. The reduction in drag

can explain higher swimming velocities observed in triathletes using a wetsuit (Toussaint, H. M. 1990).

Chatard, J. C. et al (1995) examined the time taken to swim 400m by competitive swimmers and triathletes who were wearing either a wetsuit or standard swimming trunks. Triathletes improved 22 seconds or 30 metres for a 400m swim wearing a wetsuit. Competitive swimmers did not improve. It is likely that the potential performance gain from wearing a wetsuit is affected by the velocity at which the swimming event is conducted (Bentley, D. J. et al 2002).

In a study by Cordain, L. and Kopriva, R. (1991) on comparing the use of wetsuits and normal swimsuits on 14 competitive female swimmers, it was shown that wearing wetsuits reduced swim times for the 400m (-4,9%) and 1500m swim (-3,23%) compared with swimsuit trials. Wearing wetsuits, swim times were inversely related to density for the 400m and 1500m swim suggesting that wetsuits increase performance by increasing buoyancy and that lean subjects benefit more than fatter subjects (Cordain, L. and Kopriva, R. 1991).

The thickness of the wetsuit may not exceed 5mm so as to limit the buoyancy advantage provided by the wetsuit (Chatard, J. C. et al 1995). When compared with highly skilled swimmers, triathletes with inferior swimming ability would require a greater energy expenditure in the swimming stage of triathlon when a wetsuit is not able to be used. It is possible that the

increased energy requirement will result in a decrease in performance during the subsequent cycling and running stages of the event (Bentley, D. J. et al 2002).

Neoprene, the material used in wetsuits, is less dense than fat and improves flotation more than fat and significantly reduces the frontal area that a swimmer presents to the water. In addition, since a wetsuit covers the trunk and legs but not head, it shifts a swimmers centre of buoyancy towards the feet and puts a swimmer in a more horizontal position which further reduces the frontal surface area which makes direct contact with water. Simply put, swimmers with wetsuits become more streamlined. It has been suggested that the wetsuit design in combination with physical characteristics of a swimmer may influence the change in swim performance obtained when using a wetsuit (Chatard, J. C. et al 1996).

Drafting during cycling

In most circumstances the most effective way of reducing aerodynamic drag is to cycle behind other riders, a technique known as drafting. Drafting may reduce air resistance by up to 40% if the gap between the cyclists is 0,3m and by about 35% if the gap is 0,5m. This translates into a power saving of 20% – 30% for the cyclist (Stegmann, J 1989, Hausswirth, C. and Lehenaff, D 1999, Hausswirth, C. et al 2000). It has also been shown that cycling behind a pack of eight riders results in a much larger decrease in energy cost than does drafting behind one, two or four riders, (McCole, S. D. et al 1990), therefore

existing data demonstrates that participating in triathlons involving a draft legal cycle stage results in a considerable energy saving. (Bentley, D. J. et al 2002).

The reduced energy expenditure during the cycling stage in draft legal triathlons results in an improvement in running performance (Hausswirth, C. 1999 and 2000). Hausswirth et al (1999) showed that elite triathletes performed the final five kilometres of a sprint triathlon significantly faster after they drafted behind one cyclist than when they did not draft during the cycle stage. They also noted that the benefits of drafting during the cycle stage were higher for stronger runners. Pedalling frequency as well as other physiological demands of the cycle stage of a triathlon may also have an influence on the triathletes running ability (Bentley, D.J. et al 2002).

Drafting during Swimming

The opportunity to draft behind or to the side of other swimmers makes triathlon swimming unique from competitive lane-based pool swimming (Bentley, D. J. et al 2002). The depression made in the water by a leading swimmer decreases the passive drag of the following swimmers by 10% – 26% (Chatard, J. C. et al 1998, Chollet, D. et al 2000, Millet, G. P. et al 2000). Drafting during swimming also leads to a 5% – 10% decrease in oxygen uptake (VO_2) at sub-maximal and maximal velocities reflecting greater economy (Chollet, D. et al 2000, Basset, D. R. et al 1991). Performance improvements of between 3.2% and 6% have been shown to occur during drafting by swimmers (Chatard, J. C. et al 1998).

Delextrat, A et al (2003) in a study investigating the effects of drafting (ie swimming directly behind a competitor) while swimming with a wetsuit, on cadence and physiological parameters during subsequent cycling in triathletes, indicated from the results that cycling efficiency was significantly improved (+4,8%, P<0,05) when the cycling session was preceeded by swimming in a drafting position compared with an isolated swimming bout (Delextrat, A et al 2003).

2.8 Fractional Utilisation of Maximal Capacity

The fractional utilisation of maximal capacity (%VO_{2max}) represents both the effects of VO_{2max} and economy of motion. %VO_{2max} can also represent how close to VO_{2max} an athlete can perform during competition. The fastest pace that an athlete can sustain during an endurance event is thought to require an energy output just below that at which lactate progressively accumulates in muscle and blood causing metabolic acidosis (O' Toole, M. L. et al 1995). In triathlon racing the energy output and the %VO_{2max} representing the lactate threshold may vary among the three events. Lactate threshold has been reported to range from 72 – 88%VO_{2max} for cycling and 80 – 85%VO_{2max} for treadmill running (Kohrt, W. M. et al 1989, O'Toole, M. L. et al 1989). These thresholds are comparable to those reported for competitive cyclists and runners. For the triathletes, lactate thresholds during swimming, cycling and running may all occur at different energy outputs, different %VO_{2max} and different heart rates.

2.9 Muscle Strength and Endurance

Upper body strength has been demonstrated to be one of the major determinants of success in sprint swimming. There is a strong positive relationship between a swimmer's strength and the ability to develop power. However, as the competition distance increases the contribution of strength appears to diminish. Since the swimmer's endurance and speed depend on the muscles ability to produce force and energy, individual differences in performance can in some ways be related to these characteristics in arm and leg muscles.

One characteristic of muscle that has gained considerable attention from the world of sport is the muscle composition of fast (FT) and slow twitch (ST) fibres. The nerve cells that control these fibres determine whether they will be FT or ST fibres. The muscle fibres and their connecting nerve system are referred to as a motor unit.

In general, the ST motor units are characterised as having good aerobic endurance and appear to be recruited most often during low intensity endurance events. Superior endurance cycling performance has been associated with a greater number of ST fibres and an increased oxidative capacity of these fibres (Sjogaard, G. 1984, Coyle, E. F. et al 1991).The FT motor units develop considerably more force than the ST motor units but fatigue rather easily. FT fibres are therefore used during shorter, faster races. Traditionally, weight training for muscular strength and power has been

associated with athletes requiring improvements in short-term athletic performance. Typically these athletes posses a greater size of FT muscle fibres (Tesch, P. A. 1988). During slow, low intensity swimming, most of the muscle force is generated by the ST fibres.

As the load increases and therefore the muscle tension requirements increase, FT fibres are added to the work force therefore athletes who have a high percentage of ST fibres might have an advantage in endurance events whereas those with a predominance of FT fibres could be better suited to short explosive activity (50m – 200m swimming events). Sprinters have a marked predominance of FT fibres in their leg muscles while long distance runners have a marked predominance of ST fibres (Saltin, B. et al 1976).
Although there are tendencies for swimmers to have a high percentage ST fibres in their shoulder muscles (Deltoid) than non athletes, muscle fibre composition does not appear to be a prerequisite for success in competitive swimming. Most studies have reported that the composition of muscle appears fixed and unaffected by training and therefore suggest that this quality of athletic ability may be inherited. Though elite sprinters and endurance performers in other sports (for example running and cycling) can be characterised by the percentage of ST or FT fibres, sprint and distance swimmers do not differ in this regard. Therefore the swimmer's fibre composition appears to have little bearing on success in competition.

Morgan, D. W. and Craib, M (1992) suggest that inter-individual differences in running economy may be related to differences in muscle fibre type.

However, Williams, K. R. and Cavanagh, P. R. (1987) reported no difference in fibre type among trained runners with good, medium and poor running economy. Since neural adaptations improve the ability of the nervous system to appropriately activate the muscles, a proper firing pattern must be developed for each of the three events in a triathlon (O'Toole, M. L. et al 1995).