Review Article

Long distance triathlon: demands, preparation and performance

PAUL B. LAURSEN ✉

New Zealand Academy of Sport Auckland, New Zealand
Sport Performance Research Institute New Zealand (SPRINZ) School of Sport and Recreation Auckland University of Technology Auckland, New Zealand
School of Exercise, Biomedical and Health Sciences Edith Cowan University Joondalup, WA, Australia

ABSTRACT

Laursen PB. Long distance triathlon: demands, preparation and performance. *J. Hum. Sport Exerc.* Vol. 6, No. 2, 2011. The rise in worldwide popularity of long distance triathlon racing comes with it an increased interest into how to train and prepare optimally for such an event. This paper examines the physiologic and bioenergetic demands of long distance triathlon racing, including energy requirements, muscle damage consequences, thermoregulatory demands and water turnover rates. In response to these physiological challenges, the second part of the paper describes the training goals and race practices that may assist to minimize these disturbances, in turn, optimising performance and health for the long distance triathlete. Some of these race strategies include appropriate pacing, ensuring adequate fluid and carbohydrate consumption, acclimating to the heat, and consuming caffeine in appropriate quantities. **Key words:** ULTRA-ENDURANCE, IRONMAN, TRIATHLETE, EXERCISE, CARBOHYDRATE, DRINKING

INTRODUCTION

On February 18, 1978, fifteen competitors began the world's first Ironman triathlon event off the beach of Waikiki, in Honolulu, Hawaii. It's unlikely that any of those competing at the time could have foreseen the international craze that it has become, with now, at the time of writing, consisting of 24 sanctioned Ironman events throughout the world under the Ironman World Triathlon Corporation trademark, that are considered qualifiers for the Hawaii Ironman World Championship in Kona on Hawaii's Big Island. There are another 42 sanctioned 70.3 Ironman Triathlon (half-Ironman) events, which can also be qualifiers for the World Championship. And of course, there are numerous other Ironman and half-Ironman distance triathlon events, or similar, around the world. All events tend to have participation levels that range from between 500 to 2500 competitors. Importantly, people are no longer considered odd, as they might have at one time, for engaging in training for such events. Instead, this hobby is well accepted and considered part of a healthy lifestyle (Neubauer et al., 2008; Wagner et al., 2010).

The rise in worldwide popularity of long distance triathlon racing comes with it an increased interest into how to train and prepare optimally for such an event. In order to uncover opportunities to enhance long distance triathlon performance, this paper takes a practitioners approach to the problem by examining first the physiological demands of the event, including energy and water requirements, thermoregulatory demands and resulting muscle damage. Second, the paper will describe the preparation required to create physiological defense systems for each fatigue-causing factor. Last, the paper will offer strategies for maximizing race day performance; approaches that include heat acclimation, tapering, carbohydrate ingesting, caffeine supplementation and using thirst to optimize hydration.

DEMANDS OF LONG DISTANCE TRIATHLON

In the context of this review, a long distance triathlon is considered an 'ultra-endurance' triathlon, where ultra-endurance is defined as moderate to high-intensity (threshold intensity, e2-e3) exercise performed for durations longer than 4 hours (Kreider, 1991; Hawley and Hopkins, 1995). Such triathlons include the half- (1.9 km swim, 90 km bike, 21.1 km run) and full distance Ironman (3.8 km swim, 180 km bike, 42.2 km run) races. Half Ironman event times tend to range from 3.8 to 7 h in duration, and full Ironman events from 8 to 17 hours, depending of course on the fitness level and efficiency rates of the athlete (Laursen and Rhodes, 2001). Performing such long duration work at relatively high intensities (~80% maximum heart rate; Laursen et al., 2005) requires high energy expenditures, elicits a rise in core temperature and causes generally large water turnover rates, muscle damage and a high incidence of muscle cramping.

Bioenergics
Estimates of energy expenditure approximate 4500 kcal for half-Ironman triathlons (Gillum et al., 2006) and 8500 to 11,500 kcal for full Ironman races (Laursen and Rhodes, 2001; Kimber et al., 2002). With energy contribution from the immediate (ATP-CP) and short-term (anaerobic glycolytic) energy systems considered relatively insignificant, performance in an ultra-endurance triathlon will be dependent on both the rate and efficiency of oxygen-derived adenosine triphosphate (ATP) repletion. As protein oxidation is relatively small during exercise, carbohydrate and lipid oxidation rates become a main determinant of race success in an ultra-endurance triathlon. As outlined by Hawley and Hopkins (1995), the pathways for carbohydrate and lipid oxidation in muscle mitochondria include the aerobic glycolytic and lipolytic systems, respectively. The aerobic glycolytic system refers to one's capacity to use carbohydrate (breakdown of glucose to pyruvate, to acetyl CoA, through the Krebs cycle and electron transport chain) to derive ATP aerobically, while the aerobic lypolytic system describes one's capacity to break down triglycerides to fatty acids (lipolysis), to

acetyl CoA (β-oxidation), to be also run through the Krebs cycle and electron transport chain to derive ATP aerobically.

With ultra-endurance exercise, there is a progressively greater use of fat as fuel over the duration of the event, until it can contribute up to 80% of the total caloric expenditure (Golnick, 1985). Cross-sectional studies on trained versus untrained athletes show that endurance training increases the ability to oxidise fat stores from both intramuscular triglycerides and adipocytes (Coggan et al., 2000). Thus, intelligent and demanding training is the key to increasing the capacity for aerobic glycolytic and lipolytic capacity (Laursen, 2010). Training program theory and plans that have been shown to be successful for both age group as well as elite triathletes will be discussed subsequently in the section on 'training'.

Core temperature

The chemical energy conversion of macronutrients to the mechanical energy that powers a triathlete around an Ironman course elicits an accompanying release of energy in the form of heat (~75%). While this energy gives us our warm blooded temperatures required for life, it can also lead to problems when our heat-producing metabolic rate becomes greater than our ability to release it from our body. This imbalance is usually seen as a rise in core temperature.

Core temperature, both during and after an Ironman triathlon, has been reported to range from between 34.2 and 40.5°C (Sharwood et al., 2002, 2004; Laursen et al., 2006, 2009). Thus, both hypothermia (Sharwood et al., 2002, 2004) and hyperthermia can be experienced; the latter occurrence particularly in hot races (Laursen et al., 2009). Such high body temperatures are associated with fatigue-related reductions in speed (Laursen et al., 2009). For example, Laursen et al. (2009) presented a case study of an Ironman triathlete performing in a hot (35°C) Ironman Western Australia race, where the triathlete slowed markedly after reaching a core temperature of 39.4°C.

Heat transfer in the body occurs through the processes of radiation, conduction, convection and evaporation. The most powerful of these heat removal processes (~75%) for the exercising human is the evaporation of sweat, which releases 580 kcal per litre of sweat evaporated from the skin. As described by Noakes (2006), this adaptation is an advantage we share with only a few other animals, and one that enabled our successful evolution, as we ran for long distances in the heat of the Savanna desert, chasing our prey, that were unable to continue further in such heat. While we humans are well-evolved to perform ultra-endurance exercise, our high sweat rates means that water is removed from our body at high rates, and must therefore be replaced at appropriate rates. What exactly is an appropriate rate will be the topic of the next section.

Body weight changes, water balance and hyponatremia

Body mass changes following an Ironman triathlon have been reported to range from between -10.7% and +3.7% (Speedy et al., 1997; Sharwood et al., 2004; Laursen et al., 2006; Hew-Butler et al., 2007). While it is often thought that the main contributor to body mass loss during an Ironman will be the aforementioned sweat rate, another significant source of body mass loss, not always appreciated, will be the mass lost in the form of oxidized substrate (stored carbohydrate, lipid and protein), generally thought to be in the range of 1-2 kg (Pastene et al., 1996). Another potential source of body mass loss is the water that is lost when glycogen is oxidized. Recall that when 1 g of glycogen is stored in skeletal muscle, approximately 3 g of water is also stored with it (Jeukendrup and Gleeson, 2010). Once muscle glycogen stores (~450 g) are oxidized during an ultra-endurance triathlon, the water that was stored with it (~1 L) must be released back into the body. Thus, a triathlete can expect to lose between 2-3 kg of mass in the form of stored substrate

and water over the course of ultra-endurance event (Brouns, 1991; Pastene et al., 1996; Speedy et al., 2001). To illustrate, Laursen et al. (2006) showed that well-trained Ironman triathletes performing a ~10 h Ironman Western Australia lost 2.3±1.2 kg (~3%). Moreover, none of these athletes required medical attention. Thus, well-trained Ironman triathletes should expect to lose about 3% of their body mass (~2-3 kg) over the course of an Ironman event, without any adverse consequences.

In fact, athletes that either do not lose much mass, or gain mass during the course of an ultra-endurance event from drinking, are more likely to develop a dilutional hyponatremia (Speedy et al., 1997, 2001; Noakes, 2010), as defined as a serum sodium concentration less than 135 mEq·L^{-1}. For example, Speedy et al. (1997) showed an inverse relationship between postrace sodium concentrations and percentage change in body weight (r = -0.63) in the New Zealand Ironman.

Hyponatremia has been reported as a common medical occurrence in Ironman triathlons since the early 1980's. For example, Hiller et al. (1987) showed that 27% (17/64) of studied athletes requiring medical care in the 1982-1985 Hawaii Ironman triathlons were hyponatremic following the race. Initial attempts to lower the occurrence of hyponatremia were to supplement with sodium tablets during the race, but these studies showed no effect of salt supplementation (Speedy et al., 2002; Hew-Butler et al., 2006). While fluid overload appears to be the main cause of hyponatremia (Speedy et al., 1997, 2001; Noakes, 2010), it can still occur when athletes lose body mass. For example, in the aforementioned case study (Laursen et al., 2009), the athlete lost 2% of his body mass during a hot (33.1°C) Ironman, but still became hyponatremic at the halfway point of the marathon run (131 mEq·L^{-1}). While a high fluid consumption during the cycle phase (1.71 L·h^{-1}), which exceeded this athletes' sweat rate (1.42 L·h^{-1}), was a potential cause of the hyponatremia, another could have been a heat- and/or exercise-induced oversecretion of arginine vasopressin (AVP; Hew-Butler et al., 2008). Thus, the peak high core temperature (39.4°C) mentioned previously that likely caused the triathlete to slow may also have stimulated a nonosmotic AVP secretion, leading to fluid retention and a dilutional hyponatremia (Laursen et al., 2009). Indeed, Speedy et al. (2001) have also shown that hyponatremia can develop with modest levels of fluid intakes.

Drinking guidelines for long distance triathletes
Guidelines for drinking have been heavily debated in recent years. Earlier recommendations based on laboratory studies recommended that athletes should drink early, and as much fluid as tolerable (Sawka and Coyle, 1999), or at levels that match sweat rate (Convertino et al., 1996). This message, purported heavily in the media and through commercial interests, created a fear of dehydration for athletes and practitioners, that continues to resonate within the industry to this day (Noakes, 2008, 2010).

Noakes (2007) argues however that athletes can safely gauge fluid replacement using their innate serum osmolality-based thirst mechanism. That is, that we will drink to our level of thirst, which is governed by hypothalamic osmoreceptors that relay information pertaining to the level of blood osmolality. What may happen in some cases of athletes performing long distance triathlons, especially during the latter stages of an event, is that the pain, fatigue and slowing of pace that generally occurs (Abbiss and Laursen, 2008), may be interpreted incorrectly as a sign of dehydration, which could prompt an athlete to drink and confound the problem. One initiative put in place by both New Zealand and South African Ironman races, has been to reduce the number of drink stations available on the course, to lower the opportunity to drink. This action has successfully lessened the occurrence of hyponatremia in long distance triathlon racing, and is an action that should be followed by long distance triathlon race organizers throughout the world (Sharwood et al., 2002, 2004; Wharam et al., 2006).

In summary, there is no reason I can see why athletes need specific recommendations for fluids volumes, as these will depend largely on sweat rates, that will be influenced by environmental temperatures, metabolic rates and resulting core temperatures. Thus, the best advice for athletes competing in a long distance triathlon is to ensure there is availability of fluids, but to drink according to thirst.

Muscle cramps

Exercise-associated muscle camping is defined as involuntary painful skeletal muscle spasms that occur during or immediately after physical exercise (Schwellnus et al., 1997). In long distance triathletes, these are typically localized in the calf, hamstring or quadriceps muscles. While this is a common occurrence found during or after a long distance triathlon, the aetiology and risk factors for cramping remain somewhat unclear and controversial. Traditional hypotheses state that heat (Armstrong et al., 2007), dehydration and electrolyte imbalances (Eichner et al., 2007) are the cause of such cramping. However, a number of studies have now convincingly shown no relationship between the occurrence of such cramping and either dehydration or electrolyte changes in marathon runners (Schwellnus et al., 2004) or Ironman triathletes (Sulzer et al., 2005; Schwellnus et al., 2010). Instead, a recent study by Schwellnus et al. (2010) showed that a history of muscle cramping and an overall faster race time were the main predictors of exercise-associated muscle cramping in 210 triathletes competing in the South African Ironman. In this study, triathletes who cramped also tended to predict faster overall cycle and run times before the race, and attempted to cycle and run faster during the race, compared with non-cramping athletes who reported similar past performances (Schwellnus et al., 2010). These findings compare with the case study by Laursen et al. (2009), that showed an athlete performing the first 60 minutes of the marathon run phase at a high intensity (14 km·h^{-1}) that caused his core temperature to reach 'critical levels' (39.4°C), before he slowed, cramped severely at the halfway point of the marathon run, and walked the remaining 21 km. This athlete had a history of faster races, and a desire to finish much faster than he did (Laursen et al., 2009).

These aforementioned findings support Schwellnus et al.'s (1997) 'muscle fatigue' cramping model, suggesting that 'neuromuscular fatigue' leads to abnormal neuromuscular control, namely an increase in muscle spindle afferent activity, a reduction in Golgi tendon organ afferent activity, and a resulting increase in alpha motor neuron activity and the muscle spasm observed (Schwellnus et al., 1997). The practical application of this information is that long distance triathletes need to pace themselves at speeds closer to, or slightly below, those that are practiced (O'Toole, 1989), so as to avoid excessive fatigue and resulting muscle cramps (Laursen et al., 2009). This idea will be expanded on in both the subsequent training and pacing sections of the manuscript.

Muscle damage

One of the revealing signs of the physical toll placed on the long distance triathlete is the degree of muscle damage it inflicts. This has been characterized by muscle soreness, loss of muscle function, and reductions in aerobic capacity (Suzuki et al., 2006; Nosaka et al., 2010). For example, Suzuki et al. (2006) showed reductions in muscle strength and jump height, with accompanying increases in muscle soreness, blood markers of muscle damage, and inflammation in the 24 h period following an Ironman triathlon.

The majority of the muscle damage that occurs during a long distance triathlon originates from the eccentric-based contractions of the run phase (Farber et al., 1991). Moreover, the run phase performance tends to be most highly correlated to overall long distance triathlon performance (Laursen et al., 2005; Knechtle et al., 2010). Thus, training appropriately to run a marathon following long distance swimming and cycling is important. Specific run training results in adaptations that reduce muscle damage following subsequent bouts of exercise. In time, fibres are regenerated, and adaptations in the connective tissue

provide greater resilience to insult during the critical long distance triathlon event (Ebbeling & Clarkson, 1989). Such adaptations create more resilient and elastic muscle fibres and tendons, lessen muscle damage and pain, and improve run performance ability. Of course, significant muscle damage occurs irrespective of training level, and may actually be higher in well trained athletes due to the higher run speeds, greater muscle mass engaged, and reduced amount of walking relative to less trained triathletes. Regardless, a well-trained triathlete can recover from this muscle damage within approximately one week (Nosaka et al., 2010).

PREPARATION FOR LONG DISTANCE TRIATHLON

Bioenergetic goals

The outlined demands of the long distance triathlon highlight that fitness level from training makes the largest influence towards reducing the impact that these stresses have on the triathlete during a long distance triathlon, and the resulting performance. With respect to bioenergetics, success in the triathlon will stem from the ability of the triathlete to oxidise macronutrients at high rates and to transfer this energy to the mechanical energy needed to power the triathlete around the triathlon course. The energy required will be mainly provided through oxidative phosphorylation in the mitochondria of the active muscles, and the three inputs include oxygen, free adenosine diphophate and inorganic phosphate, and reducing equivalents. The reducing equivalents are derived from the metabolism of fat and carbohydrate, which are mobilized from intramuscular stores, adipose tissue, liver and exogenously ingested carbohydrate (Spriet, 2007). Exercise training creates a cascade of signals (Coffee and Hawley, 2007) that put into motion an upregulation of defense systems that permit 1) an increase in the rate of energy production from both aerobic pathways, 2) a tighter metabolic control (i.e., matching ATP production with ATP hydrolysis), 3) an increased economy of motion, and therefore 4) less fatigue in working muscles during exercise (Hawley and Spargo, 2007).

Kimber et al. (2002) showed in recreational triathletes competing in the New Zealand Ironman event, that total energy expenditure approximated 10,000 kcal, but that energy intake (94% carbohydrate) was around 4000 kcal. Thus, about 6000 kcal of energy originates from endogenous (stored) macronutrient sources during an Ironman event (Kimber et al., 2002). Hence, there is an obvious need for both high rates of fat and carbohydrate oxidation. Carbohydrate stores in the body however are limited, with a typical well-trained male athlete storing around 450 g of carbohydrate (~350 g as muscle glycogen, ~95 g as liver glycogen and ~5 g as circulating blood glucose). This approximates 1800 kcal of energy. Subtracting this 1800 kcal of endogenous carbohydrate from the pre-calculated 6000 kcal energy deficit, leaves 4200 kcal that must be oxidised from endogenous protein and lipid sources during an Ironman event. With oxidation of amino acids from endogenous protein stores thought to be minimal, the ability to oxidise fat and carbohydrate at high rates will contribute highly to long distance triathlon success.

Training principles

With respect to training for a long distance triathlon, there are probably a number of different ways one could go about it (Laursen, 2010). Nevertheless, the basic principles of training include progressive overload, specificity, frequency, duration, intensity, and recovery (Lambert et al., 2008). The foundation of any exercise training program is the principle of progressive overload. This could be achieved by progressively increasing how long you train for in a session (duration), how hard you perform that session (intensity), how often you perform your training (frequency) and how much (or little) recovery or rest is inserted between your sessions. The principle of specificity states simply that you get what you train for, and for the long distance triathlete, time spent swimming, cycling and running needs to be relatively high.

With respect to training frequency, this will depend on the level of the athlete, and the stage of the program, but it is not unusual for an elite triathlete to perform two or three disciplines in a given day on multiple days (O'Toole, 1989).

Exercising for long durations is a critical part of training for the long distance triathlete. When exercise is prolonged, this depletes carbohydrate reserves, and the continuation of exercise relies more and more on fat as a fuel source. Such training elicits important adaptations during the recovery phase that will permit more fat to be used earlier on in a subsequent training session, thereby reducing the formation of lactic acid, slowing the rate of glycogen breakdown and reducing phosphocreatine use (Hawley, 2002). This adaptation plays a major role in the increased endurance ability shown after training. Training intensity also has a profound effect on acute changes in fitness levels (Laursen and Jenkins, 2002). While the acute benefits of high-intensity training are impressive, the ability to perform such training is limited, and too much high-intensity training can lead to overtraining (Billat et al., 1999).

Typical long distance triathlete practices

Not surprising, the training practices of long distance triathletes and their beliefs regarding the program that best leads to success tends to vary (O'Toole, 1989; Gulbin and Gaffney, 1999). In 242 recreationally-trained triathletes competing at the Lanzarote Ironman triathlon, Gulbin and Gaffney (1999) reported that athletes spent 21.5 ± 10.8 weeks preparing, and on average, swam 8.8 ± 4.3 km·wk⁻¹, cycled 270 ± 107 km·wk⁻¹, and ran 58.2 ± 21.9 km·wk⁻¹, at paces of 1 min 48 s·100m⁻¹, 31.8 km·hr⁻¹, and 4.55 min·km⁻¹, respectively. These data compare with those reported earlier by O'Toole (1989), where athletes, on average, swam, cycled and ran, approximately 11.5 km·wk⁻¹, 363 km·wk⁻¹ and 72 km·wk⁻¹, respectively; although distance and training pace varied substantially. O'Toole (1989) noted from her study that younger and faster triathletes (less than 10.5 h in the Hawaii Ironman Triathlon) tended to train greater distances and at faster paces. However using regression analysis, Gulbin and Gaffney (1999) noted that long distance triathlon performance was predicted by previous best Olympic distance triathlon performance, weekly cycling distance and longest training ride ($R^2 = 0.57$). This potential importance of cycle training for the long distance triathlete is expanded on in the practical training recommendation section below.

Practical training recommendations

The aforementioned principles of any exercise training program are important to appreciate for the high performing triathlete. The systematic way upon which these principles get organized and put into practice fall under the concept of periodization, which is the art of varying the training session, its intensity, its duration, how often its performed, and how much rest and recovery is performed in between (Lambert et al., 2008). In terms of the distribution of intensity and volume in the program of any endurance athlete's training program, it is becoming increasingly clear that an 80:20 distribution of training, in terms of the percentage of training completed below and above the ventilatory threshold, may be optimal (Laursen, 2010; Seiler, 2010). While it is unclear why this distribution may be optimal, it may be that such a training intensity distribution elicits an appropriate degree of molecular signaling to the genes that transcribe the proteins responsible for mitochondrial biogenesis and substrate handling, while at the same time, preserving autonomic balance of the organism (Laursen, 2010; Seiler, 2010).

When one first compares the Ironman distance triathlon with the Olympic distance triathlon (1500 m swim, 40 km cycle, 10 km run), roughly four times the distance, the initial thought is that completing the Ironman distance must require four times the training. Interesting however, in a comparison between elite short and long-distance British triathletes, with the exception of swim speed, which was faster in short-distance triathletes, there was no difference in maximal or submaximal physiological characteristics (i.e., maximal

oxygen uptake, economy or thresholds) measured in cycling and running between the groups (Millet et al., 2003). Such a finding suggests that training programs might also be similar between short and long distance elite triathletes, and in this authors observations, this tends to be the case with both elite short and long distance triathletes tending to train around 30 hours per week. While the training level and physiological capacities of swimming, cycling and running compares between the triathlon distance specialists, there may be a slightly different training discipline emphasis, specifically with respect to a greater volume and intensity of cycle training, a greater volume of run training, and a reduced volume of swim training for the successful long distance triathlete (O'Toole, 1989; Gulbin and Gaffney, 1999). The greater fitness generated from the higher volume and intensity of cycle training creates the fatigue resistance that enables a long distance triathlete to cycle 90 or 180 km quickly and relatively less fatigued before running a marathon or half marathon successfully.

Example training plans

While there are an infinite number of ways one can design a training program, it can be helpful to observe programs that have shown some success. Tables 1, 2 and 3 show weekly training program examples for novice (12-14 h), well-trained (10-11 h) and elite (<9.5 h) long distance triathletes preparing for an Ironman.

Table 1. *Example of an elite Ironman triathlete training program (sub 9 h 30 min). Training sessions will vary in accordance with the training cycle with the total weekly training time being 30 ± 3 h. Training sessions in italics are training sessions that would be added to the general training regime in peak training volume periods.*

Day of the Week	Swim	Bike	Run
Monday	REST	REST	REST
Tuesday	Strength (TD = 4000m)		Long run 2 – 3h (can include race specific speeds)
Wednesday	Race specific (TD = 3500)	Higher intensity interval e.g. 8 x 4 min (E3/E4) 2 min recovery	*30 -50 min E1*
Thursday		2 h – 2 h 30 min (E1	50 – 1 h 15 min run (include negative split e.g. 25 min E1, 25 min E2ii)
Friday	Aerobic Development (TD = 4000-4500)	*1 h 30 min – 2 h (E1)*	Race specific run e.g: 8 x 2 km (descend in 2's, 2@E2, 2@E2i, 2@E2ii, 2@E3, 2@E4)
Saturday		Long ride 5- 7 h (E1)	
Sunday	Aerobic Development (TD = 3500)	3-4 h ride inc ~80% of time at Ironman Race pace (E2i-E2ii)	45-60 min run off the bike (80% include target Ironman race pace; E2i – E2ii)

TD = Total distance. E1 = Endurance training zone 1 (<VT$_1$). E2i = Endurance training zone 2 one (>VT$_1$ to < VT$_2$, lower end). E2i = Endurance training zone 2 two (>VT$_1$ to < VT$_2$, upper end). E3 = Endurance training zone 3 (equal to VT$_2$, threshold). E4 = Endurance training zone 4 (>VT$_2$)

Table 2. *Example of a well-trained Ironman triathlete training program (sub 10 h to 12 h). Training sessions will vary in accordance with the training cycle with the total weekly training time being 20 ± 3 h.*

Day of the Week	Swim	Bike	Run
Monday	REST	REST	REST
Tuesday	Strength (TD = 2000m)	Higher intensity interval e.g. 8 x 4 min (E3/E4) 2 min recovery	
Wednesday	Race specific (TD = 3500)		Long run 1.5 – 3 h
Thursday		2 h ride E2	
Friday	Aerobic Development (TD = 3000- 3500)		Race specific run e.g: 6-8 x 2 km (descend in 2's, 2@E2, 2@E2i, 2@E2ii, 2@E3, 2@E4)
Saturday		Long ride 4- 6 h (E1)	
Sunday		2-3 h ride inc ~80% of time at Ironman Race pace (E2i-	45-60 min run off the bike (80% include target Ironman

Table 3. *Example of a novice Ironman triathlete training program (> 12 h). Training sessions will vary in accordance with the training cycle with the total weekly training time being 12 ± 2 h.*

Day of the Week	Swim	Bike	Run
Monday	REST	REST	REST
Tuesday		Higher intensity interval e.g. 9 x 5 min (1@E2i, 1@E2ii, 1@E3) 2 min recovery	
Wednesday	Strength (TD = 3000-4000m)		
Thursday		Ride 1.5 h (E1)	
Friday	Race specific (TD = 2500)		Race specific run e.g: 6-8 x 1 km (descend in 2's, 2@E2, 2@E2i, 2@E2ii, 2@E3, 2@E4)
Saturday		Long ride 3- 5.5 h (E1)	
Sunday			Long run 1.5 – 2.5 h

TD = Total distance. E1 = Endurance training zone 1 (<VT$_1$). E2i = Endurance training zone 2 one (>VT$_1$ to < VT$_2$, lower end). E2i = Endurance training zone 2 two (>VT$_1$ to < VT$_2$, upper end). E3 = Endurance training zone 3 (equal to VT$_2$, threshold). E4 = Endurance training zone 4 (>VT$_2$)

LONG DISTANCE TRIATHLON PERFORMANCE

Pre-event preparation

While the previous section was centered on long-term preparation for an ultra-endurance triathlon, the following section will focus on the final two weeks leading into the event. Short-term pre-race strategies that have shown success at improving acute performance include tapering, heat acclimation and ensuring adequate carbohydrate, fluid and caffeine ingestion.

Tapering

The taper is the phase of the training program characterized by reduced training load in the final days leading up to major competition (Mujika, 2010). The aim of this phase is to lower accumulated fatigue of the prior intensive training block, maximize physiological adaptations and consequently improve long distance triathlon performance. This is generally achieved by reducing the number of training sessions, making them less intense or shorter in duration. The challenge for the long distance triathlon coach is to design a taper that avoids detraining, and retains or improves adaptations and subsequent performance. Tapering specifically for the triathlete is reviewed thoroughly in this symposium, and for more information on the topic the reader is referred to the work in this issue of the journal (Mujika, in press).

Heat acclimation

Long distance triathlons usually take place in summer months and as a result tend to be performed in conditions of high ambient temperatures. These warm environments create a unique physiological challenge – not only must blood be distributed to working muscles to power the athlete over the triathlon course, but substantial blood must also be diverted to the skin to dissipate excess heat. One strategy that has been found to successfully improve performance is the act of heat acclimation (Lorenzo et al., 2010). Heat acclimation has been shown to induce a number of positive physiological adaptations, including reduced oxygen uptake at a given power output, muscle glycogen sparing, reduced blood lactate at a given power output, plasma volume expansion, improved myocardial efficiency and increased ventricular compliance. Using a 10-day heat acclimation program (90 min cycling at 50%VO_{2max} in 40°C, 30%rh), Lorenzo et al. (2010) showed improvements in one-hour time trial performance in hot (38°C, 30%rh; +8%) and cool conditions (13°C, 30%rh, +5%) in well trained cyclists. Heat acclimation also increased plasma volume, power output at lactate threshold, maximal cardiac output and VO_{2max} relative to the control group that performed the same 10-day exercise protocol under cool conditions. These findings indicate that heat acclimating could be of benefit for the long distance triathlete irrespective of whether or not it happens to be hot on race day. Although it may be difficult to find the facilities needed to create the warm environment required for this maneuver, the triathlete may be able to perform a modified version of the protocol used by Lorenzo et al. (2010) by completing light exercise in the heat over the final days leading up to their event.

Carbohydrate loading

The availability of carbohydrate as a substrate for muscle metabolism and central nervous system support is a critical contributor to long distance triathlon performance (Burke, 2010). As mentioned, total body carbohydrate stores are limited, and are substantially less than the fuel requirements of the long distance triathlon. Therefore, in an effort to boost these limited stores, carbohydrate loading, or consuming carbohydrate intakes of 10-12 g·kg^{-1}·day^{-1} over the 36-48 hours leading up to competition, are often promoted to improve performance (Burke, 2007). For example, Rauch et al. (1995) showed that three days of carbohydrate loading improved power output during a 3 h high intensity cycling trial in eight endurance trained cyclists. In line with this study, it seems prudent to endorse similar recommendations and for athletes to consume 10-12 g·kg^{-1}·day^{-1} over the 36-48 hours leading up to a long distance triathlon.

Hydration

As mentioned earlier in the review, the importance of hydration status on exercise performance may have been previously overstated (Noakes, 2008). Nevertheless, it seems prudent to ensure adequate hydration to the level of one's thirst. Adequate water levels are also required to store the glycogen goals of carbohydrate loading. This was shown indirectly in the study by Laursen et al. (2006), where athletes were 1 kg heavier 30 min prior to starting their Ironman event than when weighed just two days prior to the Ironman.

Caffeine

In 2004, caffeine was removed from the list of prohibited substances of the World Anti-Doping Agency, meaning that athletes can consume caffeine either in their background diets or for the specific purposes of performance enhancement without fear of sanctions. Not surprisingly then, caffeine was reported to have been used by 89% of athletes competing in the 2005 Hawaii Ironman triathlon, and at levels that would be considered to be performance enhancing (Desbrow and Leveritt, 2006). While the mechanisms of how caffeine enhances prolonged performance are not entirely clear, the potentially beneficial effects include the mobilisation of fat from adipose tissue and the muscle cell, stimulation of epinephrine release, direct effects on cardiac muscle, direct changes to muscle contractility and alterations to the central nervous system to change perceptions of effort or fatigue (Burke, 2008). With performance enhancing levels shown to be around the 3 mg·kg^{-1} dose level, this seems an appropriate dose to recommend for long distance triathletes. Pill or tablet form tends to be the best way to ensure that the appropriate dosage is taken, as certain products that claim to have caffeine in them also contain other substances that could compete with caffeine's effect. As levels tend to peak about an hour after consumption, this seems an appropriate period to ingest caffeine prior to race start. Furthermore, re-ingestion of this dose every 3 h seems logical to balance the caffeine removal rates. Of course, there are a number of side effects (Burke, 2008), and athlete need to experiment with their chosen dosage in practice before using caffeine in an important long distance triathlon event.

Event considerations

The training is completed, the pre-race preparation is in place and the race has begun. What practices now might assist to give the long distance triathlete the best performance they can achieve on the day? The final ingredients towards optimising long distance triathlon performance may now come down to appropriate nutrition in the form of carbohydrate and fluid consumption, and pacing strategy.

Carbohydrate assimilation

As established throughout the manuscript, the energy demands of a long distance triathlon are high. Once the race has begun, it is important to supplement the muscle cells with a source of exogenous carbohydrate to provide the reducing equivalents required for the needed high aerobic metabolic rates. High carbohydrate ingestions rates have been shown to be related to long distance triathlon performance. For example, in male triathletes, Kimber et al. (2002) showed that Ironman finishing time was inversely related to carbohydrate intake (g·kg^{-1}·h^{-1}) during the marathon run (r = – 0.75, p < 0.05). As such, increasing carbohydrate intake during may be a useful strategy for improving Ironman performance.

Just how much carbohydrate a triathlete should ingest during ultra-endurance exercise has received an increase in interest of late. Previously, it was found that carbohydrate oxidation was limited to 1 g·min^{-1} due to a saturation of SGLT1 glucose transporters. However, by using a mix of glucose and fructose in the carbohydrate source, it was shown that carbohydrate delivery and oxidation could be increased to 1.75 g·min^{-1}. This increased carbohydrate absorption occurs via fructose absorption through the GLUT5

transporter, which is converted to glucose in the liver. The increased carbohydrate oxidation with multiple transportable carbohydrates is also accompanied by increased fluid delivery and improved oxidation efficiency, and with this, a reduced likelihood of gastrointestinal distress (Jeukendrup, 2010). Recent studies have also shown reduced fatigue and improved exercise performance with multiple transportable carbohydrates compared with single carbohydrate sources, and for review, the reader is referred to the recent work of Jeukendrup (2010).

Hydration guidelines

Guidelines for drinking have been discussed thoroughly in this manuscript and will not be extended further. Hydration requirements will fluctuate with environmental condition and metabolic rate, and it appears that the most prudent advice is to drink throughout a long distance triathlon in accordance with thirst (Noakes, 2007). Because environmental conditions are sometimes not known until after the gun goes off, a potential strategy may be to have a variety of more (gels, cola) and less (weak carbohydrate-electrolyte) concentrated drinks available for use during the bike and run phases, to self-administer carbohydrate and fluid levels according to requirements. It is more than likely that most athletes do this intuitively during long distance triathlon racing.

Pacing

The pacing strategy, or how fast or slow one chooses to perform an event, is known to have an influence on performance outcome (Abbiss and Laursen, 2008). For example, O'Toole (1989) have shown that faster finishers in the Hawaii Ironman Triathlon were able to maintain their training paces throughout all three activities of the triathlon. Typically, long distance triathletes perform a positive pacing strategy, characterized by a fast initial pace, and then a reduction in pace throughout the remainder of event (Laursen et al., 2002, 2005). This has been shown as a decline in heart rate at an average rate of 1–2% per hour during a long distance triathlon (Laursen et al., 2005). Similarly, power output and speed has been shown to decrease during the 180-km cycle phase of an Ironman triathlon (Abbiss et al., 2008). It is believed that this progressive reduction in exercise intensity may be the result of glycogen depletion, neuromuscular fatigue, and/or psychological factors associated with the perception of fatigue (Abbiss and Laursen, 2008). While it is difficult to do so, long distance triathletes are advised to attempt to perform an even pacing strategy, and to perform their long distance triathlon at a pace that is similar to that which is performed in training (O'Toole, 1989).

SUMMARY

In summary, long distance triathlons, including half and full distance Ironman events, require prolonged (>4 h) durations of moderate to high intensity exercise, which mostly use energy from the oxidation of fat and carbohydrate in the range of 4500 and 11,500 kcal. Long distance triathlon training programs generally consist of long duration cycling and running completed at relatively fast speeds. Such training improves fat oxidation rates, lowers lactate production, spares glycogen and increases fatigue resistance. Pre-event preparation strategies include the taper, ensuring adequate hydration, carbohydrate loading, acclimating to the heat, and consuming 3 mg·kg^{-1} of caffeine one hour prior to race start. During long distance triathlon racing, athletes should pace themselves by performing at speeds that resemble those practiced in training, consuming up to 1.75 g·min^{-1} of carbohydrate using a mix of fructose and glucose and drinking according to thirst.

ACKNOWLEDGEMENTS

REFERENCES

1. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. Sports Med. 2008;38(3):239-52.
2. Abbiss CR, Quod MJ, Martin DT, Netto KJ, Nosaka K, Lee H, Surriano R, Bishop D, Laursen PB. Dynamic pacing strategies during the cycle phase of an Ironman triathlon. Med Sci Sports Exerc. 2006 Apr;38(4):726-34.
3. Armstrong LE, Casa DJ, Millard-Stafford M, et al. American College of Sports Medicine position stand. Exertional heat illness during training and competition. Med Sci Sports Exerc 2007;39:556–72.
4. Bentley DJ, Cox GR, Green D, Laursen PB. Maximising performance in triathlon: applied physiological and nutritional aspects of elite and non-elite competitions. J Sci Med Sport. 2008 Jul;11(4):407-16. Epub 2007 Sep 14.
5. Billat VL, Flechet B, Petit B, Muriaux G, Koralsztein JP. Interval training at VO2max: effects on aerobic performance and overtraining markers. Med Sci Sports Exerc. 1999 Jan;31(1):156-63.
6. Brouns F. Heat-sweat-dehydration-rehydration: a praxis oriented approach. J Sports Sci 1991;9:143–152.
7. Burke LM. Fueling strategies to optimize performance: training high or training low? Scand J Med Sci Sports. 2010 Oct;20 Suppl 2:48-58.
8. Burke LM. Nutrition strategies for the marathon: fuel for training and racing. Sports Med. 2007;37(4-5):344-7.
9. Burke LM. Caffeine and sports performance. Appl Physiol Nutr Metab. 2008 Dec;33(6):1319-34.
10. Coffey VG, Hawley JA. The molecular bases of training adaptation. Sports Med. 2007;37(9):737-63
11. Coggan AR, Raguso CA, Gastaldelli A, Sidossis LS, Yeckel CW. Fat metabolism during high-intensity exercise in endurance-trained and untrained men. Metabolism. 2000 Jan;49(1):122-8.
12. Convertino VA, Armstrong LE, Coyle EF, et al. American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc. 1996;28: i–vii.
13. Desbrow B, Leveritt M. Awareness and use of caffeine by athletes competing at the 2005 Ironman Triathlon World Championships. Int J Sport Nutr Exerc Metab. 2006 Oct;16(5):545-58.
14. Ebbeling CB, Clarkson PM. Exercise-induced muscle damage and adaptation. Sports Med. 1989 Apr;7(4):207-34.
15. Eichner ER. The role of sodium in 'heat cramping'. Sports Med 2007;37:368–70.
16. Farber HW, Schaefer EJ, Franey R, Grimaldi R, Hill NS. The endurance triathlon: metabolic changes after each event and during recovery. Med Sci Sports Exerc. 1991 Aug;23(8):959-65.
17. Gillum TL, Dumke CL, Ruby BC. Muscle glycogenolysis and resynthesis in response to a half Ironman triathlon: a case study. Int J Sports Physiol Perform. 2006 Dec;1(4):408-13.
18. Gollnick PD. Metabolism of substrates: energy substrate metabolism during exercise and as modified by training. Fed Proc. 1985 Feb;44(2):353-7.
19. Gulbin JP, Gaffney PT. Ultraendurance triathlon participation: typical race preparation of lower level triathletes. J Sports Med Phys Fitness. 1999 Mar;39(1):12-5.
20. Hawley JA, Spargo FJ. Metabolic adaptations to marathon training and racing. Sports Med. 2007;37(4-5):328-31.

21. Hawley JA. Adaptations of skeletal muscle to prolonged, in- tense endurance training. Clin Exp Pharmacol Physiol 2002; 29: 218-22

22. Hawley JA, Hopkins WG. Aerobic glycolytic and aerobic lipolytic power systems. A new paradigm with implications for endurance and ultraendurance events. Sports Med. 1995 Apr;19(4):240-50.

23. Hew-Butler T, Jordaan E, Stuempfle KJ, et al. Osmotic and nonosmotic regulation of arginine vasopressin during prolonged endurance exercise. J Clin Endocrinol Metab. 2008;93:2072–2078.

24. Hew-Butler T, Collins M, Bosch A, Sharwood K, Wilson G, Armstrong M, Jennings C, Swart J, Noakes T. Maintenance of plasma volume and serum sodium concentration despite body weight loss in ironman triathletes. Clin J Sport Med. 2007 Mar;17(2):116-22.

25. Hew-Butler TD, Sharwood K, Collins M, Speedy D, Noakes T. Sodium supplementation is not required to maintain serum sodium concentrations during an Ironman triathlon. Br J Sports Med. 2006 Mar;40(3):255-9.

26. Hiller WD, O'Toole ML, Fortess EE, Laird RH, Imbert PC, Sisk TD. Medical and physiological considerations in triathlons. Am J Sports Med. 1987 Mar-Apr;15(2):164-7.

27. Jeukendrup AE, Gleeson M. (2010) Sport Nutrition: An Introduction To Energy Production And Performance. Human Kinetics Publishers.

28. Jeukendrup AE. Carbohydrate and exercise performance: the role of multiple transportable carbohydrates. Curr Opin Clin Nutr Metab Care. 2010 Jul;13(4):452-7.

29. Kimber NE, Ross JJ, Mason SL, Speedy DB. Energy balance during an ironman triathlon in male and female triathletes. Int J Sport Nutr Exerc Metab. 2002 Mar;12(1):47-62.

30. Knechtle B, Wirth A, Rosemann T. Predictors of race time in male ironman triathletes: physical characteristics, training, or prerace experience? Percept Mot Skills. 2010 Oct;111(2):437-46.

31. Kreider RB. Physiological considerations of ultraendurance performance. Int J Sport Nutr. 1991 Mar;1(1):3-27.

32. Lambert MI, Viljoen W, Bosch A, Pearce AJ, Sayers M. Chapter 1: General Principles of Training. In: The Olympic Textbook of Medicine in Sport. Volume XIV of the Encyclopaedia of Sports Medicine. IOC Medical Commission Publication. Edited by M.P. Schwellnus. Blackwell Publishing Ltd., West Sussex, UK, 2008.

33. Laursen PB. Training for intense exercise performance: high-intensity or high-volume training? Scand J Med Sci Sports. 2010 Oct;20 Suppl 2:1-10.

34. Laursen PB, Rhodes EC, Langill RH, McKenzie DC, Taunton JE. Relationship of exercise test variables to cycling performance in an Ironman triathlon. Eur J Appl Physiol. 2002 Aug;87(4-5):433-40. Epub 2002 Jun 26.

35. Laursen PB, Rhodes EC. Factors affecting performance in an ultraendurance triathlon. Sports Med. 2001;31(3):195-209.

36. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. Sports Med. 2002;32(1):53-73

37. Laursen PB, Suriano R, Quod MJ, Lee H, Abbiss CR, Nosaka K, Martin DT, Bishop D. Core temperature and hydration status during an Ironman triathlon. Br J Sports Med. 2006 Apr;40(4):320-5.

38. Laursen PB, Knez WL, Shing CM, Langill RH, Rhodes EC, Jenkins DG. Relationship between laboratory-measured variables and heart rate during an ultra-endurance triathlon. J Sports Sci. 2005 Oct;23(10):1111-20.

39. Lepers R. Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007. Med Sci Sports Exerc. 2008 Oct;40(10):1828-34.

40. Lorenzo S, Halliwill JR, Sawka MN, Minson CT. Heat acclimation improves exercise performance. *J Appl Physiol* 109: 1140 –1147, 2010.
41. Millet GP, Dréano P, Bentley DJ. Physiological characteristics of elite short- and long-distance triathletes. Eur J Appl Physiol. 2003 Jan;88(4-5):427-30. Epub 2002 Nov 19.
42. Neubauer O, König D, Kern N, Nics L, Wagner KH. No indications of persistent oxidative stress in response to an ironman triathlon. Med Sci Sports Exerc. 2008 Dec;40(12):2119-28.
43. Noakes TD. Changes in body mass alone explain almost all of the variance in the serum sodium concentrations during prolonged exercise. Has commercial influence impeded scientific endeavour? Br J Sports Med. 2010 Dec 22. [Epub ahead of print]
44. Noakes TD. Hydration in the marathon: using thirst to gauge safe fluid replacement. Sports Med. 2007;37(4-5):463-6.
45. Noakes TD. Oral fluids: how pseudoscience gulls the gullible. S Afr Med J. 2008 Jun;98(6):410, 412
46. Noakes, T.D. The limits of endurance exercise. Basic Res Cardiol 101:408–417 (2006).
47. Nosaka, K., C.R. Abbiss, G. Watson, B. Wall, K. Suzuki, and P. Laursen. Recovery following an Ironman triathlon: A case study. European Journal of Sports Science. 10, 3 (2010): 159-165.
48. O'Toole ML, Douglas PS, Laird RH, Hiller DB. Fluid and electrolyte status in athletes receiving medical care at an ultradistance triathlon. Clin J Sport Med. 1995;5(2):116-22.
49. O'Toole ML.Training for ultraendurance triathlons. Med Sci Sports Exerc. 1989 Oct;21(5 Suppl):S209-13.
50. Pastene J, Germain M, Allevard AM, et al. Water balance during and after marathon running. Eur J Appl Physiol Occup Physiol 1996;73:49–55.
51. Rauch LH, Rodger I, Wilson GR, Belonje JD, Dennis SC, Noakes TD, Hawley JA. The effects of carbohydrate loading on muscle glycogen content and cycling performance. Int J Sport Nutr. 1995 Mar;5(1):25-36.
52. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exerc Sport Sci Rev 1999;27:167–218.
53. Schwellnus MP, Drew N, Collins M. Increased running speed and previous cramps rather than dehydration or serum sodium changes predict exercise-associated muscle cramping: a prospective cohort study in 210 Ironman triathletes. Br J Sports Med. 2010 Dec 9. [Epub ahead of print]
54. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? Int J Sports Physiol Perform. 2010 Sep;5(3):276-91.
55. Schwellnus MP, Nicol J, Laubscher R, et al. Serum electrolyte concentrations and hydration status are not associated with exercise associated muscle cramping (EAMC) in distance runners. Br J Sports Med 2004;38:488–92.
56. Schwellnus MP, Derman EW, Noakes TD. Aetiology of skeletal muscle 'cramps' during exercise: a novel hypothesis. J Sports Sci. 1997 Jun;15(3):277-85.
57. Sharwood KA, Collins M, Goedecke JH, Wilson G, Noakes TD. Weight changes, medical complications, and performance during an Ironman triathlon. Br J Sports Med. 2004 Dec;38(6):718-24.
58. Sharwood K, Collins M, Goedecke J, Wilson G, Noakes T. Weight changes, sodium levels, and performance in the South African Ironman Triathlon. Clin J Sport Med. 2002 Nov;12(6):391-9.
59. Speedy DB, Faris JG, Hamlin M, Gallagher PG, Campbell RG. Hyponatremia and weight changes in an ultradistance triathlon. Clin J Sport Med. 1997 Jul;7(3):180-4.
60. Speedy DB, Noakes TD, Kimber NE, Rogers IR, Thompson JM, Boswell DR, Ross JJ, Campbell RG, Gallagher PG, Kuttner JA. Fluid balance during and after an ironman triathlon. Clin J Sport Med. 2001 Jan;11(1):44-50.

61. Speedy DB, Thompson JM, Rodgers I, Collins M, Sharwood K, Noakes TD. Oral salt supplementation during ultradistance exercise. Clin J Sport Med. 2002 Sep;12(5):279-84.
62. Spriet LL. Regulation of substrate use during the marathon. Sports Med. 2007;37(4-5):332-6.
63. Sulzer NU, Schwellnus MP, Noakes TD. Serum electrolytes in Ironman triathletes with exercise-associated muscle cramping. Med Sci Sports Exerc 2005;37:1081–5.
64. Suzuki K, Peake J, Nosaka K, Okutsu M, Abbiss CR, Surriano R, Bishop D, Quod MJ, Lee H, Martin DT, Laursen PB. Changes in markers of muscle damage, inflammation and HSP70 after an Ironman Triathlon race. Eur J Appl Physiol. 2006 Dec;98(6):525-34. Epub 2006 Oct 10.
65. Wagner KH, Reichhold S, Hölzl C, Knasmüller S, Nics L, Meisel M, Neubauer O. Well-trained, healthy triathletes experience no adverse health risks regarding oxidative stress and DNA damage by participating in an ultra-endurance event. Toxicology. 2010 Dec 5;278(2):211-6. Epub 2009 Sep 18.
66. Wharam PC, Speedy DB, Noakes TD, Thompson JM, Reid SA, Holtzhausen LM. NSAID use increases the risk of developing hyponatremia during an Ironman triathlon. Med Sci Sports Exerc. 2006 Apr;38(4):618-22.
67. Zouhal H, Groussard C, Minter G, Vincent S, Cretual A, Gratas-Delamarche A, Delamarche P, Noakes TD. Inverse relationship between percentage body weight change and finishing time in 643 forty-two-kilometre marathon runners. Br J Sports Med. 2010 Dec 15. [Epub ahead of print]