

Physiological Strategies to Improve Performance at Ironman Wales Triathlon

Triathlon is an event comprising the individual disciplines of swimming, cycling and running, performed in that order without stopping during competition (Borrego-Sánchez *et al.*, 2021). Between each discipline, there is a transition where each triathlete changes equipment to face the next discipline. Therefore, triathletes must complete two transitions, the first from swimming to cycling (T1), and the second from cycling to running (T2) (Cuba-Dorado, Álvarez-Yates, and García-García 2022). Although race distances vary, triathlons of all distances can be considered to be endurance events (Knechtle, Wirth and Rosemann, 2010; Suriano and Bishop, 2010). However, Grealy *et al.* (2012) explain the Ironman distance consisting of swimming 2.4 miles (3.8 km), cycling 112 miles (180 km), and running 26.2 miles (42.2 km) is ultra-endurance, defined as an event exceeding six hours in duration (Borrego-Sánchez *et al.*, 2021) and is considered as one of the most challenging ultra-endurance events worldwide (Knechtle, Wirth and Rosemann, 2010).

Although triathlon started in San Diego, California, the history of Ironman triathlon started in 1978 in Hawaii, with the first Ironman World Championship being held in Kailua-Kona three years later (Grealy *et al.*, 2012; Borrego-Sánchez *et al.*, 2021; Knechtle, Wirth and Rosemann, 2010). Nowadays, Ironman events take place all over the world, with amateur and professional athletes competing in these events to qualify for the World Championship in Kailua-Kona which is considered one of the most extreme Ironman events due to the qualifying requirements and the severe environmental conditions encountered during the race (Knechtle, Wirth and Rosemann, 2010; Sellés-Pérez *et al.*, 2019). Having said this, it is suggested that there are a select few Ironman triathlons that are thought to be even tougher than Kona, with one of these being Ironman Wales (IMW) (Triathlon magazine, 2023). IMW is set in the heart of Pembrokeshire, South Wales and consists of a two-loop swim course at the famous North Beach in the seaside town of Tenby. Once out of the water athletes have a long run up steps into T1 before mounting their bikes ready for the two-loop bike course, with a total altitude difference of 2450 m (8038 ft) through the undulating Pembrokeshire Coast National Park. Subsequently, after dismounting at T2 the athletes take on the four-loop run course that also consists of 500 m of altitude difference, plus tens of thousands of spectators to add to the drama (IRONMAN, 2023). More so, as the event is scheduled in September environmental conditions that include ocean temperatures and surf can vary dramatically.

'Once you finish Wales you know you can finish anything' (Lucy Gossage, 2022, cited in Baird, 2023).

The rise in popularity of Ironman over the last decade has seen a growing number of recreational athletes competing with reports of 120,000 triathletes competing in 2015 with only 1% in the elite

category, whilst the remaining 99% raced in the age group categories (Sellés-Pérez *et al.*, 2019). As such, the performance level and physiological demands for each athlete competing over the Ironman distance is diverse (Maunder, Kilding, and Plews, 2018), with race times ranging from 8–8.5 and 9.0–9.5 hours in elite male and female athletes respectively, whereas low-level armatures may take up to 14-17 hours to complete the event (Dallam, Jonas and Miller, 2005).

Considering this, the intention of this review is to give an overview of potential physiological strategies an athlete could utilise prior to and during IMW to mitigate the onset of fatigue and maximise performance. However, it is proposed that the performance level of the Ironman triathlete is considered when adopting any recommendations.

Physiological demands of IMW

As with all endurance events, performance is physiologically determined by the athletes aerobic power defined by the maximum oxygen uptake ($\dot{V}O_{2\max}$) (Burtcher, Nachbauer and Wilber, 2011). However, due to the extreme duration of ultra-endurance events such as IMW sub-maximal parameters such as the first ventilatory (VT_1) and/or lactate threshold (LT_1) are of greater importance as they represent an intensity that can be maintained for the full duration of the event (Suriano and Bishop, 2010). Furthermore, as events such as IMW require repeated, prolonged use of muscle structures during several hours of swimming, cycling and running the physical effort has a major impact on the neuromuscular function of the muscles involved (García-manso *et al.*, 2011). Considering this, Borrego-Sánchez *et al.* (2021) suggest triathletes train specifically to improve their performance in competitions through structuring their training appropriately to cause the necessary adaptations and avoid over training. More so, as fatigue during prolonged exercise is most often associated with muscle glycogen depletion and reduced blood glucose concentrations (Cermak and van Loon, 2013) the nutritional strategy in preparation and during IMW will ultimately be essential to success. Finally, as IMW is defined by its undulating bike and run course, it is suggested that body weight will play a major role as performance is ultimately governed by the resistance an athlete must overcome to generate movement (Mujika and Padilla, 2001).

Training intensity distribution

Of the essential training variables, exercise intensity and its distribution is probably the most critical and heavily debated (Seiler and Kjerland, 2006; Sanders, Myers and Akubat, 2017). Training intensity is generally classified into three zones: Zone 1 (Z1) corresponds to low intensity exercise; Zone 2 (Z2) corresponds to moderate intensity; and Zone 3 (Z3) corresponds to high intensity (Borrego-Sánchez *et al.*, 2021). An extensive discussion on training zones and physiological thresholds would be beyond

the scope of the present review. For a more detailed description the reader is referred to Seiler (2010) and Garcia-Tabar and Gorostiaga (2021).

Two basic models of TID have emerged from the literature (Seiler and Kjerland, 2006). The threshold-training model (THR) is characterized by organising a large percentage of training at or near the lactate threshold (Seiler and Kjerland, 2006) and is considered a reasonable option for recreational athletes with a relatively modest training volume (Muñoz and Varela-Sanz, 2018). In contrast, the polarized training model (PTM) is characterized by the accumulation of the most training time in zone 1 and a minor training time in zone 3 (Kenneally, Casado and Santos-Concejero, 2018; Filipas *et al.*, 2022). It is suggested that PTM is associated with better endurance performance perhaps as it better mimics the physical activity patterns of our ancestors, thus causing less stress on the autonomic nervous system, and therefore allowing for better recovery (Muñoz and Varela-Sanz, 2018; Esteve-Lanao *et al.*, 2007). A study involving sub-elite runners by Esteve-Lanao *et al.* (2007) revealed a PTM model was more effective when compared to a THR model in regard to performance time during a 10km cross country race (-157 ± 13 s vs. 121.5 ± 7.1 s; $p = 0.03$). Similarly, although perhaps more relevant, Muñoz *et al.* (2014) revealed that recreational triathletes preparing for an Ironman event performed better when using a training distribution focusing on accumulating a larger volume of low-intensity training, with significant inverse correlations found between both total training time and training time in zone 1 vs. performance time in competition ($r = -.69$ and $-.92$, respectively).

In light of the aforementioned, it is recommended that athletes preparing for IMW adopt a TID that focuses on a relatively large percentage of training time spent in Z1 to cause the necessary adaptations whilst also allowing for better recovery to avoid overtraining (Muñoz and Varela-Sanz, 2018).

Monitoring of training stress

An additional and relatively modern strategy to monitor and prescribe training loads is through day-to-day periodisation using heart-rate variability (HRV) (Javaloyes *et al.*, 2019). HRV focuses on the variability of successive R-R intervals and enables the detection of fatigue through the evaluation of the autonomic nervous system (ANS) which is the primary regulator of fundamental aspects of overall recovery, including delivery of oxygen and nutrients, removal of waste products, and thermoregulation by the cardiovascular system (Düking *et al.*, 2021). HRV-guided training allows new possibilities for the training load prescription according to an athlete's status, the response to the training load, and the adaptation to training (Javaloyes *et al.*, 2019). Furthermore, as with recent technological developments, particularly in wearable sensor technology, athletes are able to

purchase affordable lightweight devices to effectively monitor, analyse, and interpret a variety of parameters that reflect both acute and chronic fitness and fatigue making it an attractive investment, especially to athletes without a coach (Düking *et al.*, 2021).

A study by Javaloyes *et al.* (2019) involving well trained cyclist revealed daily training prescription based on HRV resulted in greater performance enhancement than traditional periodization with improvements in peak power output ($5.1\% \pm 4.5\%$; $P = .024$), power output at VT2 ($13.9\% \pm 8.8\%$; $P = .004$), and 40-min all-out time trial ($7.3\% \pm 4.5\%$; $P = .005$) in the HRV group. However, it is important to note that differences between groups were non-significant. More so, Figueiredo *et al.* (2023) compared traditional periodisation with HRV and also subjective self-assessment using recreational runners. The findings revealed that after 5-weeks of endurance training all three programmes improved performance in peak velocity and 5 km time trial (TT), although the greatest improvements were found in the self-assessment group ($8.4 \pm 1.8\%$; $ES = 1.41$), ($-12.8 \pm 4.2\%$; $ES = -1.97$) for peak velocity and 5km TT respectively, compared to ($6.6 \pm 1.5\%$ and $-8.3 \pm 2.8\%$; $ES = -1.20$; 1.24), ($4.9 \pm 1.5\%$ and $-6.0 \pm 3.3\%$; $ES = -0.82$; 0.68) in the HRV and traditional periodisation groups respectively. Both the aforementioned studies reported that it is reasonable to assume that changes in endurance performance following a training prescription based on HRV and also self-assessment in the study by Figueiredo *et al.* (2023) are not related to the TID, but rather to a better timing of training intensity prescription, allowing specific sessions to be performed optimally under less stress responses (Figueiredo *et al.* 2023).

Taken together, it is recommended that an athlete preparing for IMW use a multifactorial approach that monitors both objective and subjective measures of training status which may lead to the greatest endurance adaptations whilst avoiding over training (Figueiredo *et al.*, 2023).

Substrate utilisation

A further physiological consideration for Ironman triathletes, is substrate metabolism and availability (Maunder, Kilding and Plews, 2018). During prolonged exercise, carbohydrate (CHO) and fat are the primary substrates oxidised to fuel energy metabolism (Maunder, Kilding and Plews, 2018; Laursen, 2011; Cermak and van Loon, 2013; Knuiiman, Hopman and Mensink, 2015). Hawley, Brouns, and Jeukendrup (1998) explain compared with the limited capacity of the human body to store CHO (approximately 450g in a well-trained male athlete), endogenous fat depots are almost limitless and represent a vast source of fuel for exercise. However, despite greater adenosine triphosphate (ATP) yield per unit of substrate from fat, CHO metabolism produces a greater ATP yield per unit of oxygen consumption via oxidative phosphorylation in the electron transport chain (Burke, 2021), thus during intense exercise fat oxidation is limited and CHO becomes the dominant fuel (Hawley, Brouns and

Jeukendrup, 1998). As a result, when glycogen stores become depleted, the energy disposal rate from CHO is diminished, and the exercise intensity must be reduced because ATP cannot be generated at a sufficient rate (Smekal *et al.*, 2003).

Maunder, Kilding and Plews (2018) explain, estimated energy expenditure (EE) during Ironman triathlon is high (8500–11,500 Kcal), with CHO requirements estimated to be between 985-1675g which far exceed the whole-body CHO content. More so, Barrero, Erola, and Bescós (2014) reported the energy requirements of recreational athletes competing in an Ironman distance event and revealed EE was ~11,000 kcal, whereas energy intake (EI) was only ~3600 kcal, which resulted in an energy deficit of almost 70%. Considering this, athletes preparing for IMW should seek to minimise the endogenous carbohydrate cost associated with exercise at competitive intensities (Maunder, Kilding and Plews, 2018). This ability to switch back and forth between fat and CHO oxidation, depending on energy demand and substrate availability is known as ‘metabolic flexibility’ and is a characteristic of elite endurance athletes (San-Milla’n and Brooks, 2018).

In light of this, it is suggested that performance at IMW is largely determined by the ability of the athlete to mobilize and oxidize fat to spare reserves of CHO for harder efforts during the race, such as steep climbs, brief burst of power when over taking on the bike, and during the final stages of the marathon (Michalik, Danek and Zatoń, 2021; Jeukendrup and Achten, 2001). As such, specific training and nutritional strategies to enhance metabolic flexibility are recommended and will be discussed next.

Nutritional periodisation

There remains a well-documented polarised debate in regard to optimal nutrition for endurance performance (Aird, Davies and Carson, 2018; Wachsmuth *et al.*, 2022; Maunder, Kilding and Plews, 2018). On one side are advocates for a low carb/ high fat diet (LCHF) that is suggested to improve endurance performance by enabling an athlete’s relatively unlimited body fat stores to better support substrate provision, thus preventing fatigue associated with the depletion of endogenous CHO stores (Burke *et al.*, 2020). In contrast, traditional nutritional strategies for endurance athletes have typically advised high CHO availability as CHO remains the only macronutrient that can be metabolized immediately in order to provide substrates for high-intensity exercise as well as support high daily training volume (Wachsmuth *et al.*, 2022; Impey *et al.*, 2016).

With this in mind, a number of CHO periodization strategies based on the ‘train low, compete high’ paradigm whereby selected training sessions are deliberately completed with reduced CHO availability to enhance specific adaptations of skeletal muscle have been tested in athletes (Bennett *et al.*, 2021). Such metabolic adaptation may be beneficial to improve performance during prolonged

sub-maximal steady state exercise, via sparing of glycogen stores for a later utilisation (Bennett *et al.*, 2021; Purdom *et al.*, 2018). These strategies include twice per day training, fasted training, post-exercise CHO restriction and 'sleep low, train low' (Impey *et al.*, 2018). Bennett *et al.* (2021) suggest that multiple "train low" strategies maybe optimal for athletes at different stages of the training cycle. However, the so called "sleep low-train low" strategy, which includes high-intensity training in the evening to deplete glycogen stores, followed by low CHO availability overnight (i.e., sleeping low), and low-intensity training the next morning with reduced CHO availability seems most appropriate for athletes because the timing of exercise and CHO restriction minimises waking hours and maximises the duration under low CHO conditions, potentially increasing the adaptive response (Impey *et al.*, 2016; Impey *et al.*, 2018). A study by Bennett *et al.* (2021) involving trained cyclists and triathletes revealed a "sleep low-train low" strategy effectively improved performance outcomes in 20-min PPO, 5-min PPO, and FTP ($\text{W}\cdot\text{kg}^{-1}$) by 4.0%, 2.3% and 5.5% respectively. Similarly, Marquet *et al.* (2016) revealed that a "sleep low" strategy promoted significant improvements in submaximal cycling economy, as well as supramaximal cycling capacity and 10-km running time in trained triathletes. However, when Impey *et al.* (2016) compared high CHO to low CHO availability in recreational male cyclists the results revealed that although CHO restriction before and during exercise induces "work-efficient" cell signalling related to mitochondrial biogenesis, complete CHO and energy restriction in the post-exercise period reduces the activation of key signalling proteins regulating skeletal muscle adaptation.

Considering this, it is suggested that athletes preparing for IMW periodise their nutrition both "day-to-day" and "meal-by-meal" in accordance with the upcoming training workloads that have been prescribed, a concept known as "fuel for the work required" (Impey *et al.*, 2016; Impey *et al.*, 2018). This approach is likely to maintain metabolic flexibility by allowing the athlete to strategically reduce CHO availability prior to completing selected training sessions, whereas key training sessions and competition are always undertaken with high CHO availability so as to promote performance and recovery (Impey *et al.*, 2018; Bennett *et al.*, 2021). Furthermore, this approach will allow athletes not only to periodise CHO but also to restrict total energy during brief periods between key training sessions, thus leading to reductions in fat/body mass (Impey *et al.*, 2018). These reductions in body fat/mass will undoubtedly improve running performance (Sellés-Pérez *et al.*, 2019) and increase power-to-weight ratio on the bike (Ferguson *et al.*, 2009).

Race day nutrition

Given the extreme duration of Ironman distance triathlon dehydration and CHO depletion are the most likely causes of fatigue and subsequent impaired performance (Jeukendrup, Jentjens, and

Moseley, 2005). As such, one of the main goals for athletes is to manage the consumption of food and drinks prior to and throughout the race (Barrero, Erola, and Bescós, 2014). Therefore, ingestion of substantial amounts of CHO (200-300g) 3–4 hours before exercise may be an effective strategy to enhance CHO availability by providing a source of glucose in the gut for later release into the bloodstream (Jeukendrup, Jentjens, and Moseley, 2005). Furthermore, athletes are suggested to choose CHO meals that are easily digested and do not cause GI discomfort and perhaps avoid CHO ingestion altogether in the hour before exercise to avoid what is referred to as rebound hypoglycaemia (Jeukendrup, Jentjens, and Moseley, 2005). However, in contrast a review by Jeukendrup and Killer (2010) concluded that there appears to be no reason not to consume CHO before exercise as there does not seem to be any detrimental effects on performance.

In addition to CHO ingestion, athletes are generally recommended to drink between 400–600mL of fluid 2 hours before the start of the event to provide adequate hydration and allow time for the excretion of excess ingested water (Jeukendrup, Jentjens, and Moseley, 2005). Typically, 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 (Laursen, 2011). However, Barrero, Erola, and Bescós (2014) reported significant decreases in body mass after the completion of an Ironman in Spain of (-4.3 ± 1.4 kg; $-5.7\% \pm 1.9\%$, $p < 0.001$), with the losses mainly contributed to a decrease in muscle density (glycogen loss) and fat mass, although significant fluid losses of 1.3L ($-8.4\% \pm 2.9\%$) were also found. More so, the results revealed a significant and negative correlation between losses of total body water and performance during the cycling stage ($r = 0.61$, $p = 0.046$), thus supporting the well-known fact that hydration is crucial for exercise performance (Barrero, Erola, and Bescós, 2014; Jeukendrup, Jentjens, and Moseley, 2005). The greater body mass and fluid losses shown by Barrero, Erola, and Bescós (2014) was more than likely caused by the average ambient temperature and relative humidity being 26 °C (13–30 °C) and 77% (64%–94%) respectively. Considering this, it seems logical to prepare for similar losses at IMW due to the increased demands and unpredictable weather during the month of September, with the highest daily maximum temperature on record being 32°C (Met office, 2023).

Finally, Cermak and van Loon (2013) explain to achieve optimal performance during prolonged moderate- to high-intensity exercise, the exogenous provision of CHO during exercise is generally required. The performance enhancing impact is likely attributed to the sparing of skeletal muscle and liver glycogen stores and maintaining high rates of CHO oxidation (Jeukendrup, 2008). Furthermore, there appears to be evidence of a dose-response relationship, in that greater amounts of CHO ingested during an Ironman triathlon have been correlated with an improvement in performance (Cermak and van Loon, 2013). This was evident in the study by Barrero, Erola, and Bescós (2014) in

that the athletes ingesting higher amounts of CHO were able to perform better as CHO intake (g/min) was inversely related to the time ($r = -0.71$), and directly related to the speed ($r = 0.70$) during the cycling stage ($p = 0.02$), thus confirming the role of CHO in the improvement of endurance performance (Barrero, Erola, and Bescós, 2014; Jeukendrup, 2008). As such the optimal range of CHO ingestion during exercise is of great interest (Jeukendrup, 2008). There was a general understanding that exogenous CHO oxidation rates cannot exceed $1.0\text{--}1.1\text{ g}\cdot\text{min}^{-1}$ regardless of how much glucose or glucose polymers were ingested (Cermak and van Loon, 2013). Therefore, Jeukendrup (2008) explains a CHO intake of 60 g/hour was recommended. However, it now appears evident that when multiple transportable CHO's are ingested (i.e., glucose and fructose) at a high rate (1.8 g/min) peak oxidation rates significantly increase to $\sim 1.2\text{--}1.3\text{ g/min}$ and result in $\sim 20\text{--}50\%$ higher exogenous CHO oxidation rates compared with the ingestion of an isocaloric amount of glucose (Cermak and van Loon, 2013; Jeukendrup, 2008). The recent findings are partly explained by the fact that these CHO's are absorbed, at least in part, by different intestinal transport mechanisms. However, Cermak and van Loon (2013) explain to increase exogenous CHO oxidation rates it may be necessary to fully saturate glucose transporters first before any ingestion of multiple transportable CHO's. In light of this, it is now possible for well-trained endurance athletes competing in longer events to increase their CHO intake up to 90g/hour ($1.5\text{--}1.8\text{ g}\cdot\text{min}^{-1}$) provided that multiple transportable CHO's are ingested (e.g., 1.2 g/min -1 glucose plus 0.6 g/min -1 of fructose) (Cermak and van Loon, 2013; Jeukendrup, 2008).

With this in mind, it is recommended that athletes competing in IMW who have difficulty consuming such large amounts of carbohydrate during exercise, practise their nutritional feeding strategies during training to train their gut so that they are able to tolerate higher rates of CHO ingestion during competition without experiencing any gastrointestinal distress.

Summary

In summary, IMW requires the athlete to engage in continuous moderate to high intensity exercise for a duration of anywhere between 8-17 hours depending on the performance level of the athlete (Dallam, Jonas and Miller, 2005). This extreme bout of endurance will require high rates of EE and CHO utilisation that far exceed whole-body CHO content, leaving the athlete in a substantial energy deficit of around 70% (Maunder, Kilding and Plews, 2018; Barrero, Erola, and Bescós, 2014).

Considering this, it is recommended that athletes preparing for IMW adopt exercise training and nutritional practices designed to minimise the endogenous carbohydrate cost associated with competitive workloads. Possible strategies have been mentioned which include firstly, a TID that focuses on a relatively large percentage of training time spent in Z1 to maximise adaptation and

recovery; Secondly, a multi-factorial approach to monitor training status; Thirdly, a nutritional strategy to enhance metabolic flexibility and reduce body fat/mass; and finally, a race day feeding strategy to increase CHO oxidation rates and subsequent performance.

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