Are recreational athletes working too hard?: A cross-sectional study investigating the association between training intensity distribution and factors associated with Ironman performance in well-trained male triathletes.

Abstract

There is a commonly held belief in the endurance coaching community that recreational athletes 'perform their easy sessions too hard and their hard sessions too easy'. The purpose of the present study was to describe the training intensity distribution (TID) of recreational triathletes during the general preparation phase of a triathlon season, based on intensity zones and observe relationships with physiological and performance measures associated with Ironman distance triathlon. The research aimed to determine if a relatively greater percentage of moderate intensity training is more beneficial toward physiological adaptations associated with Ironman performance, when compared to a relatively large volume of training at higher intensities. **Method:** 13 male triathletes (mean ± SD: age 42.5 ± 6.17years, Weight 80.7 ± 9.5kg, Height 177.3 ± 4.2cm) participated in the study. A training observation was performed over a 6-week period, where the 4-weeks with the greatest training volume were chosen for analysis. The TID of all run and bike training sessions was quantified using continuous heart rate (HR) monitoring. During the subsequent week of the observational period each participant performed a graded exercise test to determine physiological variables including MFO, Fatmax, VT1, VT2 and VO_{2max}. Three intensity zones were used to calculate the training intensity distribution of the 4-week training period: zone 1 (moderate domain), for intensities below first ventilatory threshold; zone 2 (heavy domain), for intensities between first and second ventilatory thresholds; and zone 3 (severe domain), for intensities above second ventilatory threshold. **Results:** The TID described as percentage of time spent in zones 1, 2, and 3 respectively, were (55.6 ± 19.1%, 37 ± 15.3%, and 7.6 ± 5.1%). Significant positive correlations were found between MFO (g/m) and total training time spent in Z1 ($r = .657$, $p = .039$) and between HR at Fatmax and percentage of training time in zone 1 ($r = .697$, $p = .025$). In contrast, significant inverse correlations were found between MFO (g/m) and percentage of training time in zone 3 ($r = -.665$, $p = .036$) and also between HR at Fatmax for both total training time and percentage of training time in zone 2 ($r = -.691$, $p = .027$), ($r = -.674$, $p = .033$), and total training time in zone 3 ($r = -.641$, $p = .046$). **Conclusion:** Recreational triathletes perform a relatively large percentage of their training time in zone 2, however better physiological and performance measures are associated with a TID prioritising a relatively large percentage of training time in zone 1 and less in zones 2 and 3. The results suggest that recreational athletes competing in Ironman distance triathlons are performing

their low-intensity training too hard, whereas scheduled high-intensity training sessions are not performed hard enough. Therefore, it is recommended they adopt a TID prioritising a relatively large percentage of training time in zone 1, although future research is needed to clarify this, especially during different phases of the season.

Introduction

Triathlon is a multi-event sport, involving the completion of three continuous endurance disciplines, swimming, cycling and running in that order (Knechtle *et al.,* 2015b; Borrego-Sánchez *et al*., 2021). Millet, Vleck and Bentley (2011) explain the event can be held over numerous set distances that include Olympic distance (1.5 km swim/40 km cycle/10 km run), half-distance (half-Ironman 1.9 km swim/90 km cycle/21 km run), and full-distance (Ironman 3.8 km swim/180 km cycle/42.195 km run) (Barbosa *et al.,* 2019; Borrego-Sánchez *et al*., 2021). In addition, Suriano and Bishop (2010) reveal that although race distances may vary, all triathlons can be considered endurance events with the Ironman distance being the most popular (Knechtle, Wirth and Rosemann, 2010). Although triathlon started in San Diego (Barbosa *et al*., 2019) the history of Ironman dates back to February 18, 1978, in Waikiki, Hawaii, USA, where 15 athletes took part in the multi-sport event that consisted of a 3.8km swim, 180km cycle and a 42.195km run (Knechtle *et al*., 2015a; Barrero, Erola and Bescós, 2014). Following this, the event was moved to Kona, on the Big Island of Hawaii where it became “Ironman Hawaii” and is now considered one of the 12 toughest sporting events in the world (Knechtle *et al*., 2015a; Grealy *et al*., 2012; Barbosa *et al*., 2019). To compete at “Ironman Hawaii” athletes must qualify in one of the many Ironman qualifier races from all around the world (Knechtle *et al*., 2015b). In such races the performance level varies dramatically as pro athletes compete alongside age group athletes with race times ranging from 8 hours to greater than 15 hours in lower performing amateur athletes (Maunder, Kilding and Plews, 2018).

As with most endurance sports the main objective of triathlon is to complete the race as quickly as possible (Borrego-Sánchez *et al*., 2021). As a result, the athlete must possess sufficient aerobic capacity that enables the resynthesis of adenosine triphosphate (ATP) through adequate delivery of oxygen to the mitochondria and the availability of both carbohydrate (CHO) and lipid fuels (Burke, 2021). In light of this, measurements of physiological limitations are extremely important for endurance performance as they provide the specific work intensity that span exercise domains, as defined by their metabolic demands (Galán-Rioja *et al*., 2020). More so, González-Parra, Mora and Hoeger (2013) reveal the most common measure of aerobic capacity and predictor of triathlon performance is maximal oxygen uptake (VO_{2max}), with elite triathletes values being reported in the range of (70-90 ml/kg/min), whereas professional cyclists average values are reported to be (74 mL/kg/min) (Faria, Parker and Faria 2005). Having said this, numerous studies (Cuba-Dorado, Álvarez-Yates and García-García 2022; Cejuela, and Sellés-Pérez, 2022; Suriano and Bishop, 2010) suggest that submaximal markers such as lactate and ventilatory thresholds, and more importantly the power and/or speed at which these variables occur, may prove more influential as most triathlon races are performed at or near these intensities (Knechtle *et al*, 2015b). Furthermore, when considering the extreme duration of Ironman, a further physiological limitation that might be of relevance to athletes is substrate metabolism and availability (Maunder, Kilding and Plews, 2018).

As previously mentioned, the main substrates for energy production during exercise are fat and CHO (Lima-Silva *et al*., 2011) with CHO oxidation (CHOox) increasing linearly alongside exercise intensity, while fat oxidation (FATox) increases progressively from rest to approximately 60% VO_{2max} before decreasing gradually to zero due to glycolysis and the associated glycolytic flux (Achten and Jeukendrup, 2003). The point at which this transition in substrate utilisation occurs is known as the cross over concept and demonstrates the effect of exercise intensity on the balance of CHO and fat oxidation (Brooks, 1997; Purdom *et al*., 2018; San-Milla´n and Brooks, 2018). Lima-Silva *et al*. (2010) reveal the highest value of FATox (g/min) has been defined as the maximal fat oxidation (MFO) and the exercise intensity at which this point occurs is known as (Fatmax). **Figure 1.** shows the relative contribution of substrates in relation to increasing exercise intensity.

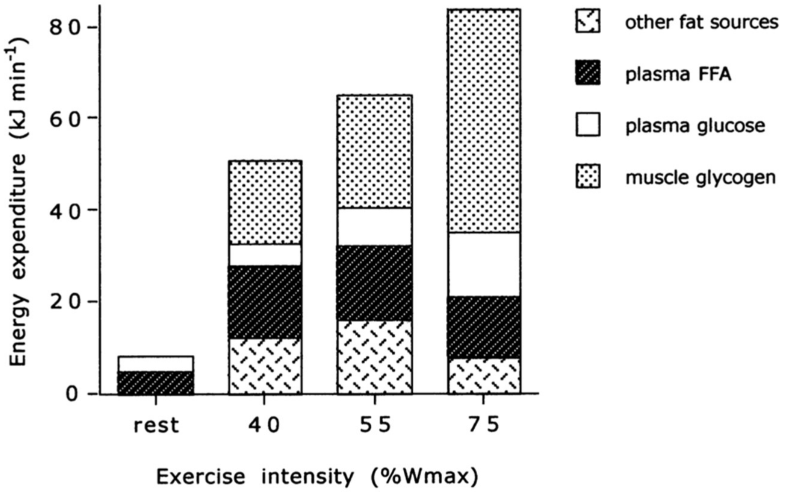

Figure 1. Energy expenditure (expressed in kJmin-1) as a function of exercise intensity [expressed in percentage of maximal workload capacity (%Wmax). The relative contribution of plasma glucose, muscle glycogen, plasma free fatty acids (FFA) and other fat sources.

(Cermak and van Loon, 2013).

With this in mind, Hawley and Stepto (2001) suggest that the most impressive training adaptation associated with endurance performance is the athletes ability to oxidise less CHO and more fat during exercise performed at the same absolute power output (PO) or oxygen uptake (VO2). A recent study by San-Milla´n and Brooks (2018) reveal that elite endurance athletes possess greater FATox, possibly due to their large volume of endurance training enhancing mitochondrial function and lactate clearance capacity. 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 considered the holy grail for endurance athletes (Burke, 2021; Brooks, 1997; San-Milla´n and Brooks, 2018; Lima-Silva *et al*., 2010). As such, submaximal thresholds such as Fatmax are important for exercise prescription as it represents an intensity for maximal fat burning potential (Purdom *et al*., 2018). Therefore, a training goal of relevance for triathletes preparing for an Ironman should be to enhance metabolic flexibility in order to preserve glycogen reserves for high intensity efforts during competition such as, steep climbs, brief bursts of power when over taking on the bike, and during the final stages of the marathon (Michalik, Danek and Zatoń, 2021).

In order to achieve these physiological adaptations coaches and athletes attempt to find the optimal combination of intensity, duration and frequency of training (Muñoz and Varela-Sanz, 2018). The manipulation of these variables at distinct stages of the season is referred to as training periodisation and to better understand, prescribe and monitor, different training zones have been created based on physiological factors such as lactate thresholds, ventilatory thresholds and percentage of heart rate (HR) (Filipas *et al*., 2022). Kenneally, Casado and Santos-Concejero (2018) reveal up to 7 zones can be used to describe training intensity. However, these numerous intensity zones suggest a degree of physiological specificity that is not really present, as the intensity zone boundaries are not clearly anchored in underlying physiological events (Seiler and Kjerland, 2006). Having said this, the ventilatory threshold approach where three training intensity zones defined by two specific ventilatory changes that correspond to the aerobic and anaerobic thresholds are most commonly used (Kenneally, Casado and Santos-Concejero, 2018; Seiler and Kjerland, 2006; Bellinger, Arnold and Minahan, 2019; Sanders, Myers and Akubat, 2017; Kenneally *et al*., 2021). In addition, the amount of time the athlete spends in each zone during training is a concept known as training intensity distribution (TID) (Filipas *et al.*, 2022), with successful endurance athletes adopting TID models including polarised (POL) and pyramidal (PYR) where up to 80% of their training is completed in zone 1 (Z1) with the remaining 20% being split into zones 2 (Z2) and 3 (Z3) (Kenneally, Casado and Santos-Concejero, 2018; Bellinger, Arnold and Minahan, 2019). These models have been consistently shown to be more effective than accumulating a high amount of training in Z2, the so called lactate threshold model (LTM) (Muñoz and Varela-Sanz, 2018).

Considering this, a key area of concern often cited throughout the literature is that recreational athletes complete their easy aerobic training too hard, whilst not working hard enough for the prescribed high intensity sessions (Muñoz and Varela-Sanz, 2018; Seiler and Kjerland, 2006). Although training at the highest intensity that can be maintained for extended periods seems reasonable, repeatedly doing so may firstly, generate excessive sympathetic stress, thus increasing the risk of over training, and secondly still not provide an optimal stimulus to create further adaptation (Seiler and Kjerland, 2006).

In light of this, the aim of the study was to use a cross-sectional design to describe the TID of well-trained male triathletes in relation to physiological and performance variables associated with Ironman distance triathlon performance. The study hypothesises that the subjects completing the largest percentage of their training in Z1, will also possess enhanced metabolic flexibility expressed through a greater MFO and Fatmax occurring at higher relative workloads.

Literature review

Traditional endurance events such as marathon running or prolonged time-trial cycling are predominately determined by the following factors: maximal oxygen consumption (VO_{2max}); lactate and/or ventilatory thresholds; and economy/efficiency i.e., the speed or power that can be achieved for a given amount of energy consumption (Millet, Vleck and Bentley, 2011; Knechtle, 2014; Maunder, Kilding and Plews, 2018; Borrego-Sánchez *et al*., 2021; Cejuela, and Sellés-Pérez, 2022). However, the physiological considerations of athletes competing in ultra-endurance triathlons such as Ironman are less well established (Maunder, Kilding and Plews, 2018). Therefore, this review will provide a brief summary of some of the traditional physiological determinants of endurance performance as well as strategies to minimise the endogenous carbohydrate cost during exercise at competitive intensities. Finally, the review will provide evidence of the strengths and weaknesses of different TID models, and the methods applied by coaches and athletes that positively affect substrate utilisation and ultimately ultra-endurance triathlon performance.

An individual's aerobic power is determined by the VO_{2max} (Burtscher, Nachbauer and Wilber, 2011). VO_{2max} describes a maximal limit for aerobic energy production (Suriano and Bishop, 2010) and is defined as the highest rate of oxygen that can be utilised by the body during severe exercise (Sellés-Pérez *et al.,* 2019; Burtscher, Nachbauer and Wilber, 2011). More so, Lee, Snyder and Lundstrom (2019) explain that a high VO_{2max} provides a greater and more efficient delivery of oxygen to peripheral tissues, facilitating the supply of energy to working muscles, making VO_{2max} an important measure of triathlon performance (González-Parra, Mora and Hoeger, 2013; Sellés-Pérez *et al*., 2019; Borrego-Sánchez *et al*., 2021; Cuba-Dorado, Álvarez-Yates and García-García, 2022). However, as anthropometric characteristics play a major role in the resistance an athlete must overcome to generate movement, physiological measures such as VO_{2max} should be scaled relative to body mass (ml/kg-1 min−1) (Mujika, and Padilla 2001; Suriano and Bishop, 2010). González-Parra, Mora and Hoeger (2013) revealed VO_{2max} values of male and female National elite triathletes to be (76.0 ml/kg-1/min-1) and (70.83 ml/kg-1/min-1) respectively, which is significantly higher than their sub-elite counterparts as Sellés-Pérez *et al*. (2019) revealed VO_{2max} values of amateur male triathletes during running and cycling to be (55.7 ml/kg-1/min-1) and (53.4 ml/kg-1/min-1) respectively. However, Suriano and Bishop (2010) suggest a further consideration when dealing with triathletes is that all three events that comprise triathlon differ in the amount of muscles used and energy required to maintain motion. As such, triathletes have been reported to possess cycle and swim VO_{2max} values that are approximately 94–97% and 74–86% respectively, of the values achieved during a running test (Butts, Henry and Mclean, 1991).

Having said this, it is suggested that VO_{2max} may not limit performance during ultra-endurance triathlons as Knechtle *et al*. (2015a) explain race effort is conducted at lower exercise intensity, with the Ironman 'Hawaii' being performed at an exercise intensity of approximately 75% of maximal heart rate (HRmax) which corresponds to the first ventilatory threshold (VT1) (Laursen *et al*., 2002). This suggests that VT1 is a more important performance intensity for events such as Ironman as it represents an intensity that can be maintained for the full duration of the event (Suriano and Bishop, 2010). During exercise with increasing intensity, three phases of the body's energy production and two threshold points delineating these phases can be distinguished (Peric *et al.,* 2022; van der Zwaard *et al*., 2016). VT1 and the second ventilatory threshold (VT2) provide two clearly defined physiological responses that can be used as a surrogate for the lactate thresholds (LT1) and (LT2) as VT1 is strongly related to the workload at which lactate starts to increase above resting values (Cerezuela-Espejo *et al*., 2018; Seiler and Kjerland, 2006). The first threshold point LT1/VT1 represents a maximum steady state that can be achieved from oxidative phosphorylation (van der Zwaard *et al*., 2016). Exercising above this threshold elevates blood lactate concentrations causing excess carbon dioxide (CO2) due to anaerobic energy production in the muscle cells as bicarbonate buffers the produced lactic acid (van der Zwaard *et al*., 2016; Coyle, 2007). More so, Anderson and Mahon (2007) suggest it is the accumulation of lactate that stimulates the increase in minute ventilation (VE) that is indicative of VT1. In addition, Gordon *et al*. (2017) explain LT2 is the point that reflects an abrupt increase in blood lactate and that any relationship with VT2 may better coincide with the maximal workload that can be maintained without elevations in blood lactate concentration, known as maximal lactate steady state (MLSS) (Cerezuela-Espejo *et al*., 2018). These metabolic thresholds separate three specific exercise intensity domains, as defined by their metabolic demands. (1) Moderate domain, <VT1/LT1, oxygen consumption (VO2) quickly reaches steady state and blood [lactate] remains at resting levels; (2) Heavy domain, >VT1/LT1, slow component of VO2 kenetics delays steady-state for up to 10-20 minutes before blood [lactate] stabilizes at an elevated level; (3) Severe domain, >VT2/LT2 where metabolic steady-state is not possible, and fatigue is imminent (Galán-Rioja *et al*., 2020). Oxygen uptake and blood [lactate] responses during moderate-intensity, heavy-intensity, and severe-intensity exercise are shown in **Figure 2.**

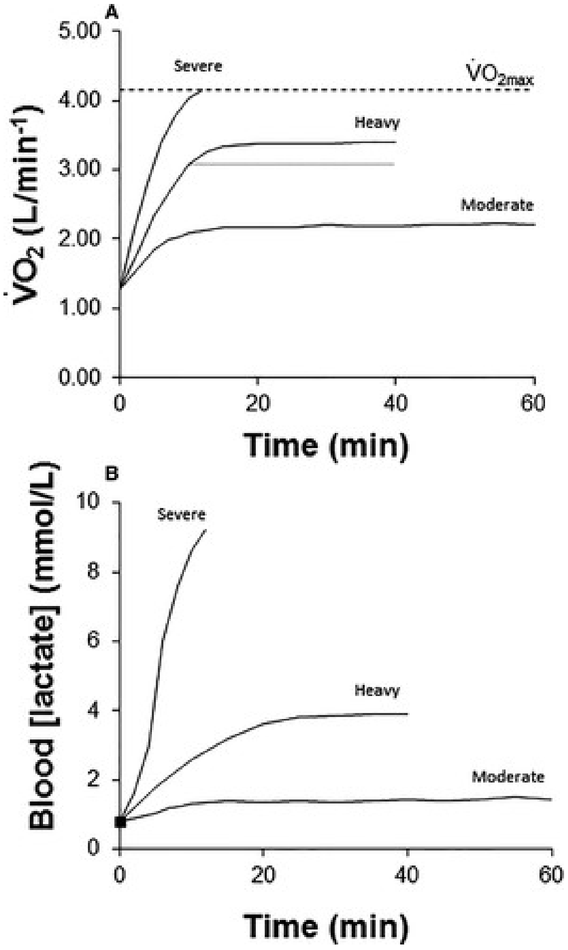

Figure 2. Oxygen uptake and blood [lactate] responses in relation to exercise intensity.

(Jones *et al.*, 2019).

There remains some debate regarding the most appropriate boundary to separate the heavy from the severe exercise-intensity domain (Galán-Rioja *et al*., 2020: Garcia-Tabar and Gorostiaga, 2021; Jones *et al*., 2019). On one side, Jones *et al*. (2019) suggest the concept of 'critical power' as the genuine boundary discriminating between heavy and severe exercise intensity domains. However, Garcia-Tabar and Gorostiaga (2021) refute this and suggest that the MLSS represents the highest workload that can be maintained without a continuous blood lactate accumulation, thus should be considered the gold-standard metric for the evaluation of endurance exercise capacity. In contrast and agreed upon by all, is that VT1 indicates the transition between moderate and heavy-intensity exercise domains (Galán-Rioja *et al*., 2020).

With this in mind, Millet, Vleck and Bentley (2011) explain VT1 values of triathletes during running and cycling have ranged from 65 to 85% and from 61 to 84% of VO_{2max} respectively. Similarly, Suriano and Bishop (2010) reported LT1 values during cycling to be 73% of VO_{2max} among a group of Ironman triathletes, with the MLSS occurring at 88% of VO_{2max}. In addition, a systematic review by Cuba-

Dorado, Álvarez-Yates and García-García (2022) revealed elite Olympic distance triathletes completed more than half the race at an intensity above VT2, with values at VT2 shown to be 84.41% and 80.5% of VO_{2max} in males and females respectively. Although the Olympic distance is considerably shorter than Ironman, these findings may have relevance as Knechtle *et al*. (2015b) explain alongside age and personal best time in marathon, the most important predictor for a fast Ironman race time is a fast personal best time in Olympic distance triathlon.

As previously mentioned a further physiological consideration for Ironman triathletes is substrate metabolism and availability as depletion of endogenous CHO is associated with fatigue (Maunder, Kilding and Plews, 2018), defined by García-manso *et al*. (2011) as any decline in muscle performance associated with the ongoing activity. Humans store the majority of CHO as glycogen within skeletal muscle (80%) and the liver (10-15%), with typical stored amounts of endogenous CHO totalling <3000 kcal (<740g) (Cermak and van Loon, 2013; Maunder, Kilding and Plews, 2018; Knuiman, Hopman and Mensink, 2015). As such, Smekal *et al*. (2003) explain due to this limited storage capacity when glycogen becomes depleted, exercise intensity must be reduced as adenosine triphosphate (ATP) cannot be generated at a sufficient rate. Despite this, Burke (2021) explain CHO is still the most important substrate during moderate to high intensity exercise due to the quicker release and greater yield of energy per litre of oxygen (5.01 vs 4.85 kcal.L-1 O2) for glycogen and fatty acid, respectively. On the contrary, Purdom *et al*. (2018) explain human fat storage is almost limitless with even the leanest of individuals (10% body fat) possessing >40,000 kcal (>5000 g) of endogenous fat energy. Endogenous fat is stored as triacylglycerols either in adipose tissue or to a smaller extent in intra-muscular sites (Hawley, Brouns, and Jeukendrup, 1998). More so, Smekal *et al*. (2003) explain, during exercise free fatty acids (FFA) are liberated and released into circulation as a product of lipolysis (breakdown of fats) where they can serve as a potential energy source for the muscle cell. However, Hawley, Brouns, and Jeukendrup (1998) suggests that lipolysis may be the limiting factor in FATox, as FATox exceeds the rate that FFA can be mobilised, consequently resulting in the use of glycogen to meet the increased energy demands. As a result, it is the athletes ability to mobilize and oxidize fat as a fuel, consequently sparing glycogen that largely determines endurance performance (Jeukendrup and Achten 2001).

The rates of energy expenditure (EE) and carbohydrate utilisation are high in elite and top-amateur Ironman triathletes, it is estimated that EE during an Ironman event may range from (8500–11,500 Kcal) at a rate of (20.1 kcal.min−1) with CHO requirement in the range of (985-1675g) (2.05–3.49 g.min−1) even with concomitant high rates of FATox (0.6–1.2 g.min−1) (Barrero, Erola and Bescós 2014; Maunder, Kilding and Plews, 2018) **Table 1.**

Table 1. Metabolic costs associated with Ironman of three different performance levels.

Phase	**Intensity**	**EE**	**Average FO (g.min-1)**	**FATox (g)**	**CHOox (g.min-1)**	**CHO cost (g)**
Elite						
Swim	1.20 m.s-1	20.4 kcal.min-1 1094 Kcal	Lower: 0.6 Upper: 1.2	32 64	3.57 2.13	192 115
Cycle	313 W	19.5 kcal.min-1 4659 Kcal	Lower:0.6 Upper: 1.2	153 305	3.35 1.92	853 487
Run	14.7 km.h-1	20.8 kcal.min-1 3572 Kcal	Lower: 0.6 Upper: 1.2	103 206	3.67 2.23	631 383
Total	8:04:07	20.1 kcal.min-1 9626 Kcal	Lower: 0.6 Upper: 1.2	288 576	3.49 2.05	1675 985
Top armature						
Swim	1.09 m.s-1	18.5 kcal.min-1 1094 Kcal	Lowe: 0.5 Upper: 1.1	30 65	3.34 1.91	198 113
Cycle	225 W	15.4 kcal.min-1 4580 Kcal	Lower: 0.5 Upper: 1.1	149 328	2.57 1.14	768 339
Run	13.5 km.h-1	18.0 kcal.min-1 3288 Kcal	Lower: 0.5 Upper: 1.1	94 207	3.23 1.79	607 337
Total	9:05:46	16.6 kcal.min-1 9062 Kcal	Lower: 0.5 Upper: 1.1	273 600	2.88 1.44	1573 788
Lower armature						
Swim	0.74 m.s-1	12.5 kcal.min-1 1094 Kcal	Lower: 0.3 Upper: 0.9	26 79	2.35 0.92	206 80
Cycle	192 W	14.8 kcal.min-1 6133 Kcal	Lower: 0.3 Upper:0.9	124 373	2.92 1.48	1209 613
Run	9.0 km.h-1	11.4 kcal.min-1 3198 Kcal	Lower: 0.3 Upper:0.9	84 252	2.09 0.65	584 182
Total	13:02:13	13.3 kcal.min-1 10.425	Lower: 0.3 Upper: 0.9	235 704	2.56 1.12	1999 875

CHO, carbohydrate; FATox, fat oxidation; CHOox, carbohydrate oxidation

(Maunder, Kilding and Plews, 2018).

A study by Barrero, Erola and Bescós (2014) involving nonprofessional male triathletes revealed during an Ironman triathlon race the estimated (EE) was (11,009 kcal ± 664 kcal), whereas energy intake (EI) was only (3643 ± 1219 kcal), which resulted in an energy deficit of almost 70%. Furthermore, the athletes consumed an average of (927 ± 178g) of CHO corresponding to (~84 g/h), and 90% of the overall EI. The findings from Barrero, Erola and Bescós (2014) clearly show the metabolic costs associated with Ironman far exceed the finite human capacity for CHO storage. Therefore, Ironman triathletes must acknowledge and prepare training and nutritional strategies designed to minimise the endogenous carbohydrate cost associated with competitive workloads (Maunder, Kilding and Plews, 2018). These training and nutritional strategies aim to ensure adequate availability and capacity to integrate the use of the muscle's fuel stores to produce ATP according to the demands of the event; a concept that is becoming known as ‘metabolic flexibility’ (Burke, 2021).

Impey *et al*. (2018) reveal strategies designed to deliberately reduce CHO availability in order to enhance endurance-training adaptations include: twice per day training, fasted training, post-exercise CHO restriction and ‘sleep low, train low’. However, in contrast, Burke (2021) suggest restricting CHO may effect performance measures through down regulating enzymes involved in CHO metabolism and therefore reducing the ability to utilise CHO when needed for high-intensity efforts. The impairment of top-end power is an area of concern for elite and high level amateur competitors who require the capacity for intermittent high power outputs during races (Maunder, Kilding and Plews, 2018). Furthermore, as well as possessing superior power output values, ranging between 349 and 525W (5.7 and 6.8 W/kg) over a 4-minute stage duration (Mujika and Padilla, 2001), it is also suggested that elite athletes possess greater metabolic flexibility as a result of the adaptations caused by endurance training (San-Milla´n and Brooks, 2018). These adaptations that include an increase in mitochondrial abundance and function that subsequently increase lactate clearance capacity and FATox at a given V’O2 (Burtscher, Nachbauer and Wilber, 2011) appeared evident in the study by San-Milla´n and Brooks (2018) who revealed significantly higher FATox in elite endurance athletes, with Fatmax occurring at 75% of peak power output (PPO) as compared to 55% in moderately trained individuals. In addition, González-Haro *et al*. (2007) revealed that FATox rates are not only varied according to the level of the athlete but also between different modalities of endurance sport where the pace of the race is developed at different relative work intensities. What the study by González-Haro *et al*. (2007) revealed was that although the Fatmax of all the endurance athletes who took part in the study presented a relative intensity of 52% VO_{2max}, the range of values varied between 43% in a subject group containing mountain bikers, whereas road cyclists and a triathlon group recorded values of 52% and 53% respectively. The authors González-Haro *et al*. (2007) suggested the reason for the significantly lower Fatmax value in the mountain biker group compared with the road cyclist and triathlon groups may be attributable to the type of training performed specific to event demands, as total competitive time developed below VT1 in high-level road cyclists and triathletes corresponds to 71.5-74.6%, compared with only 18.5% in high-level mountain bikers. With this in mind, it is important to note that the triathletes in the study by González-Haro *et al*. (2007) competed in shorter distance events which suggests athletes competing at Ironman distance would potentially possess even greater Fatmax values.

These findings support, a recent systematic review by Borrego-Sánchez *et al*. (2021) that suggest when training specifically to improve triathlon performance results show high volume and low intensity training (<VT1) as seen in TID models such as POL and PYR seems to produce superior physiological and performance adaptations in cycling and running than moderate-intensity training (>VT1), as seen in the LTM as it manages recovery better, thus minimising the accumulation of fatigue and the risk of overtraining (Filipas *et al.*, 2022; Muñoz and Varela-Sanz, 2018). The POL model is defined as having the highest percentage of time spent in Z1, a smaller but relatively high percentage in Z3 and only a small percentage in Z2 (Z1>Z3>Z2), whereas the PYR model accumulates a slightly higher percentage in Z2 and less in Z3 (Z1>Z2>Z3), although both models are characterised by the vast majority of training time being spent in Z1 (Filipas *et al.,* 2022; Bellinger, Arnold and Minahan, 2019; Kenneally, Casado, and Santos-Concejero, 2018). On the other hand, the LTM is characterised by a high amount of training time in zone 2 (Z2>Z1>Z3) and is suggested to be more demanding than POL and PYR, possibly due to the effects on the autonomic and endocrine systems (Kenneally, Casado, and Santos-Concejero, 2018; Seiler and Kjerland, 2006). However, in contrast Kenneally, Casado, and Santos-Concejero (2018) explain the LTM is used by some of the best marathon and distance runners in the world, and in order to achieve peak performance increasing relative intensity and decreasing volume of training is necessary throughout different training phases within a season to peak for important competitions, especially during the tapering phase (Filipas *et al.,* 2022; Bellinger, Arnold and Minahan, 2019). Furthermore, it is suggested that recreational athletes may also benefit more from the LTM as they don't have the ability to maintain a steady state intensity during easier sessions, whilst also not having sufficient allocated training time to accumulate enough volume at higher intensities (Muñoz and Varela-Sanz, 2018). Having said this, it has been consistently demonstrated that models such as POL and PYR are more effective than LTM for improving endurance performance in different endurance-sports modalities, not only in elite but also well-trained recreational athletes (Muñoz and Varela-Sanz, 2018; Kenneally, Casado and Santos-Concejero, 2018).

Note. All TID's in the present study will be presented as zones 1,2 and 3 respectively.

Considering this, Filipas *et a*l. (2022) investigated the effects of four different training periodizations strategies over a 16-week period in Sixty well-trained male runners. The findings revealed a TID where athletes switched from PYR to POL showed the largest improvement in measured variables including (~3.0% for relative VO_{2max}, and ~1.5% for 5-km running time trial performance). Similarly, Esteve-Lanao *et al.* (2007) also found that a TID with a relatively large percentage of low intensity training (80.5%, 11.8 %, 8.3 %) elicited significantly greater performance in 10km run time (-157 ± 13s vs. -121 ± 7.1s; p = 0.03) than a TID resembling LTM (66.8 %, 24.7 %, 8.5%) in well-trained runners over a 5-month period. On the contrary, when Muñoz *et al.* (2014b) compared POL to LTM over a 10-week training period using 30 endurance runners, results showed that although both groups significantly improved their 10Km run time (39min18s ± 4min54s vs. 37min19s ± 4min42s, P < .0001) for POL, and (39min24s ± 3min54s vs. 38min0s ± 4min24s, P < .001) for LTM, no significant difference was found between groups. In addition, when Pérez *et al*. (2020) compared the effects of 12-weeks of either POL or LTM training on fat metabolism in recreational ultra-runners, the findings revealed no change in either group for MFO or Fatmax (0.41 ± 0.24g/min vs. 0.48 ± 0.17g/min; p = .231), (48.8 ±7.8%, 47.4 ± 6.8%; p = .470) for POL and (0.44 ± 0.17g/min vs. 0.50 ± 0.24g/min; p = .404), (44.3 ± 8.6% 43.5 ± 11.0%; p =.705) for LTM respectively.

It is important to consider that these contrasting results and opinions throughout the literature regarding how endurance athletes organise their training (Bellinger, Arnold and Minahan, 2019; Seiler, 2010; Sylta, Tønnessen, and Seiler, 2014) may be in part explained by reasons that include the phase of the training season that was monitored, the method of establishing training-zone demarcations (i.e., incremental test protocol), or the training-intensity quantification method itself, as training intensity can be measured via external work rate (running speed or power output), an internal physiological response (i.e., heart rate [HR] or VO2), or by how the training is perceived (i.e., rating of perceived exertion [RPE]) (Bellinger, Arnold and Minahan, 2019). As such, it is important to recognize the most appropriate methods of monitoring training intensity to precisely quantify the TID. (Bellinger, Arnold and Minahan, 2019; Seiler, 2010). Sylta, Tønnessen, and Seiler (2014) reveal two basic approaches for quantifying endurance-training sessions, firstly the time in zone (TIZ) approach where HR data is collected and assigned to pre-determined intensity zones, and secondly the session goal (SG) approach where the entire session is assigned into an intensity zone with the assumption that the "goal portion" of the session primarily determines its impact. A study involving twenty-nine elite cross-country skiers comparing TIZ to SG showed that over 570 training sessions the proportion of training in zone 1, zone 2, and zone 3 was (96.1%, 2.9%, 1.1%) and (86.6%,11.1%, 2.4%) for TIZ and SG respectively (Sylta, Tønnessen, and Seiler, 2014). The large differences between TIZ and SG are attributed to the fact that harder sessions generally include considerable warm-up, cool-down, and recovery time between high-intensity bouts, making even the session goal, high-intensity sessions predominantly Z1 (Sylta, Tønnessen, and Seiler, 2014; Seiler, 2010).

Taking this into account and with all things considered, it is suggested that the belief that recreational athletes are working to hard may possibly be caused by a lack of knowledge due to the complexity of organising and monitoring training. Furthermore, as recreational athletes have minimal time available for training, particularly in a multi-discipline sports such as triathlon (Rosenblat *et al*., 2019; Suriano and Bishop, 2010), there is a need to determine the most optimal and effective TID to obtain the appropriate adaptations needed for events such as Ironman. Although many studies have compared the effects of different TID on physiological and performance variables in both elite and recreational athletes competing in various endurance disciplines (Kenneally *et al*., 2021; Muñoz *et al*., 2014a; Sylta, Tønnessen and Seiler, 2014; Esteve-Lanao *et al*., 2007), to the best of our knowledge no study to date has investigated the relationship of TID with physiological and performance variables in recreational ultra endurance triathletes.

Therefore, the first aim of this study was to use a cross-sectional design to describe the TID of well-trained recreational triathletes using the TIZ method to quantify training intensity into three zones, Z1 (moderate); Z2 (heavy); and Z3 (severe). A second aim was to establish any relationships between TID, and the physiological and performance measures associated with Ironman distance triathlon. The study hypothesized that the participants implementing a TID with a relatively large percentage of training time in Z1 would also possess enhanced metabolic flexibility by way of greater MFO and Fatmax occurring at a higher relative intensity when compared to the participants implementing a TID with a relatively large percentage of training time in Z2. .

Method

All lab equipment reference details are provided in **Appendix 1.**

Participants

A total of 13 male recreational-level triathletes started the study, group characteristics can be found in **Table 2**.

The participants lived and trained in the Carmarthenshire, South Wales area. Training experience in endurance sports was similar between participants ranging from 5-8 years, and although each participant had their own particular strength in either swimming, cycling or running, all had been training exclusively for triathlon since at least 2 years before the study, with no injuries within the previous 12-months. All participants provided written and verbal informed consent before any preliminary or experimental trials and Ethical approval was obtained from the University Ethics Board. The participants were required to abstain from all dietary sources of caffeine and alcohol 12 h before laboratory testing, and to avoid exhaustive exercise during the 24 h period prior to test.

Table 2. Demographics (Mean ± SD), N = 13

Variable	Mean	SD
Age (years)	42.5	6.17
Height (cm)	177.3	4.2
Weight (kg)	80.7	9.5

Experimental design

A cross-sectional research design was employed to assess the association between physiological variables and TID at a specific period of the season.

The training observation was performed over a 6-week period from January 9th – February 19th which corresponded to the general preparation phase of the season for this group of triathletes. Of this 6-week period the 4-weeks with the greatest training volume were chosen for the analysis and quantification of TID (total and percentage of time spent in each training zone) as to allow for weeks of relative inactivity caused by injury/illness or deload. The TID of all run and bike training sessions was quantified using continuous heart rate monitoring.

Testing protocol and rationale

During the subsequent week of the observational period each participant performed a graded exercise test (GXT), on an electronically braked cycle ergometer (Wattbike atom x), to determine physiological variables including MFO, FATmax, VT1, VT2 and VO_{2max}. The specific protocol utilised was designed to determine Fatmax and VO_{2max} during the same test for logistical and practical reasons. As exercise duration influences fat oxidation (Achten and Jeukendrup, 2003), it is suggested that shorter stages (1 min) and large workload increments may cause inaccurate MFO and Fatmax estimation as they do not ensure the participant reaches steady-state gas exchange measure during each stage (Amaro-Gahete *et al*., 2019). As such, Achten and Jeukendrup (2003) suggest for well-trained athletes a continuous incremental exercise test until exhaustion on a cycle ergometer with 95 W start load, 3 min stages and 35 W increments in work rate is recommended.

In contrast, to determine physiological variables such as ventilatory thresholds and VO_{2max} a protocol utilising 1 minute stages is generally recommended as it is suggested that test should last between 8 and 12 min, as prolonged tests could produce inconsistent results (Roffey, Byrne, and Hills, 2007). With this in mind, a study comparing the effect of stage duration on physiological variables associated with aerobic performance revealed that although VO_{2max} does not differ significantly between stage durations of 1 min or 3 min, longer stage durations increase the metabolic cost and elevate HR at the same workload when compared to 1 minutes stage durations, thus exercise prescription based off test results may be compromised (Roffey, Byrne, and Hills, 2007).

In light of this, a pilot study was conducted to compare the results of a GXT utilising a continuous incremental step protocol on a cycle ergometer (Wattbike atom x), with a 100 W start load, 1 minute stages and 25 W increments to a modified version (MODGXT) utilising the exact same protocol with an additional 8-minute ramp warm-up starting at 50 W, then building to 150 W before immediate commencement of the test. The additional warm up would act as one long continuous stage to allow each participant to achieve steady state, therefore more accurate determination of MFO and Fatmax (Amaro-Gahete, *et al*., 2019). The results of the pilot tests revealed no significant difference in VO_{2max}. As a result, all testing thereafter was performed utilising MODGXT.

Laboratory testing

The participants reported to the laboratory at approximately the same time of day over a one week period. Each participant was instructed to wear suitable cycling attire including cycling shoes with cleats that were compatible with the cycle ergometer (Wattbike atom x). Additionally, the participants were required to abstain from all dietary sources of caffeine and alcohol 12 h before laboratory testing, and to avoid exhaustive exercise during the 24hr period prior to test. There was no diet control, however, the participants were given instructions to consume a substantial balanced meal containing both CHO and fat on the day of testing.

Upon arrival each participant underwent anthropometric measurements for height and weight. Height was measured without shoes to the nearest 0.005 m with a stadiometer (Seca 213), whereas body mass was measured to the nearest 0.1 kg on a digital scale (Seca 875). Before testing participants were fitted on the cycle ergometer (Wattbike atom x), with seat height and handlebars being adjusted to suit, then familiarized with the Borg 6 – 20 RPE scale and the test protocol. Subsequently, participants were fitted with a mouthpiece (Hans Rudolph 2700 series large 2-way non-return breathable valve), plus a Polar transmitter chest strap (Polar H10) to record HR every 5 s throughout the test.

As previously mentioned, the test utilised was the MODGXT performed to volitional exhaustion at a self-selected cadence ranging from 70-100 rpm. The test was terminated when the cadence dropped below 60 rpm, or there was a significant plateau in VO2 detected.

Testing equipment

To measure the ventilatory variables, a gas analysis system (Coretex Metalyzer 3B) that was calibrated prior to testing using known O_2 and CO_2 concentrations (Cranlea 995/2619; 20% O2, 8% CO2) was used. A single use pre-calibrated disposable turbine attached to the inspired side of the mouthpiece (Hans Rudolph 2700 series large 2-way non-return breathable valve) measured airflow and volume. Gas exchange data was taken breath-by-breath to obtain the variables VO_{2max}, minute ventilation (VE), ventilatory equivalent for oxygen ($VE \cdot VO_2{}^{-1}$), ventilatory equivalent for carbon dioxide ($VE \cdot VCO_2{}^{-1}$), respiratory exchange ratio (RER), end-tidal partial pressure of oxygen and carbon dioxide ($PetO_2$ and $PetCO_2$ respectively). All ventilatory and HR data were transferred to a PC for subsequent analysis.

VO_{2max} was taken as the highest 30-s mean value attained prior to exhaustion in the test. After the test, the criteria used to determine VO_{2max} were, (1) a plateau produced in the VO2 curve with increases lower than 1.5 mL · kg− 1 · min− 1 between 30 s intervals; (2) RER above 1.10; and (3) a HR equal to or greater than the theoretical maximum. HRmax was recorded as the highest value obtained in the incremental test. VT1 was identified as the workload at which increases were produced in both VE·VO2 − 1 and PetO2, without a concomitant increase in VE·VCO2 − 1. Similarly, VT2 was determined when increases were produced in VE·VO2 − 1 and VE·VCO2 − 1, but this time accompanied by a drop in PetCO2.

The highest RPE taken from the final 15 s of each workload and at the culmination of the test was used as the RPE threshold indicator of maximum physical exhaustion. Following testing training-intensity zones were determined for subsequent analysis of TID.

Intensity zone determination

The three zones model was used to calculate the TID of the 4-week training period: zone 1 (moderate domain), for intensities below first ventilatory threshold; zone 2 (heavy domain), for intensities between first and second ventilatory thresholds; and zone 3 (severe domain), for intensities above second ventilatory threshold.

TID Analyses

All participants wore their own personal HR chest strap to continuously record HR data during training sessions over the 6-week observation period, with all session data subsequently downloaded and made available to the researcher via an online training diary (Training Peaks, Peaks ware LLC). Training zones were quantified according to the reference HR values obtained during the MODGXT.

TID determination

Following analysis each participants TID was described as being either POL/PYR, or LTM based on the percentage of training time performed in zone 1 (moderate), and zone 2 (heavy). As such, participants with a TID >70% in Z1 were categorised as POL/PYR, whereas participants with a TID >30% in Z2 were categorised as LTM (Rosenblat, Perrotta and Vicenzino, 2019).

Statistical analysis

The data are presented as mean values and standard deviations.
All data was uploaded and presented in Microsoft Excel, then subsequently transferred and analysed using IBM SPSS statistics, version 28. Correlations were analysed using a bivariate two-tailed Pearson product-moment coefficient to verify the existence of any relationships between the different variables measured. The significance level was determined at $p < 0.05$ for all statistical tests carried out. The effect size (ES) of the intervention was calculated using Cohen guidelines. Threshold values for ES were >0.1 (small), >0.6 (moderate), >1.2 (large).

Results

Participant Dropout

Of the 13 participants who started the study, one did not provide HR data and two did not accumulate a sufficient amount of total training volume. Thus, 10 subjects met all criteria and were included in the statistical analysis. Results of performance data from the physiological testing of the final sample included in the study are shown in **Tables 3.**

Table 3. Performance Data from the Metabolic Tests (Mean ± SD), N = 10

Variable	Mean	SD
Fat @ Fatmax (g/min)	18.2	5.9
CHO @ Fatmax (g/min)	96.8	26.8
HR @ Fatmax (bpm)	120.8	15.2
PO @ Fatmax (w)	164	42.3
Fat @ VT1 (g/min)	7.2	7
CHO @VT1 (g/min)	161.7	31.6
HR @VT1 (bpm)	142	10.2
PO @ VT1 (w)	225.5	38.1
Fat @ VT2 (g/min)	0	0
CHO @ VT2 (g/min)	239	31.3
HR @ VT2 (bpm)	163.8	6
PO @ VT2 (w)	310	35.7
Fat @ VO2max (g/min)	0	0
CHO @ VO2max (g/min)	261	32.8
HR @ VO2max (bpm)	172.3	4.9
PO @ VO2max (w)	350	39.1

Training characteristics and intensity distribution

Table 4. shows the total volume of training hours over the 4-week period was 1635.9 minutes (6hr 49 min p/w), with 589.3 minutes (36%) accumulated during run sessions, whereas 1046.6 minutes (64%) was accumulated cycling.

Figure 3. shows the greatest number of training hours was spent in Z1 (55.6% ± 19.1, 37% ± 15.3%, and 7.6% ± 5.1%) respectively, for Z1, Z2, and Z3. Of the ten participants only two were shown to be utilising a POL/PYR model, whereas the other eight utilised a LTM, as shown in **Table 5.** Individualised data of each participants TID are presented in **figures 5 and 6**.

Table 4. Training characteristics of the final sample (Mean ± SD), N = 10

Variable	Mean	SD
Total volume (min)	1635.9	310.5
Run volume (min)	589.3	255

Bike volume (min)	1046.6	202.7
Time in Z1 (min)	906.8	335.8
Time in Z2 (min)	608.7	266.1
Time in Z3 (min)	123.7	79.8
% time in Z1	55.6	19.1
% time in Z2	37	15.3
% time in Z3	7.6	5.1

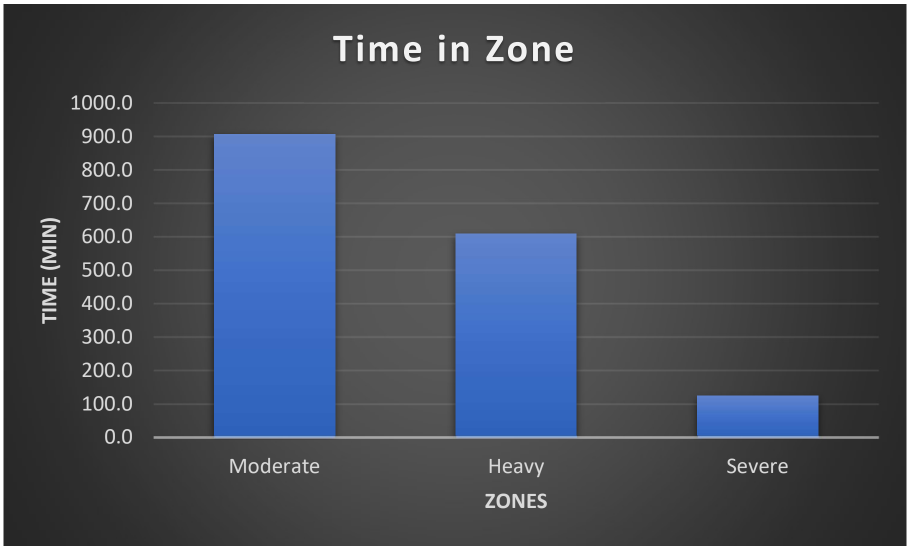

Figure 3. Total training time spent in each zone.

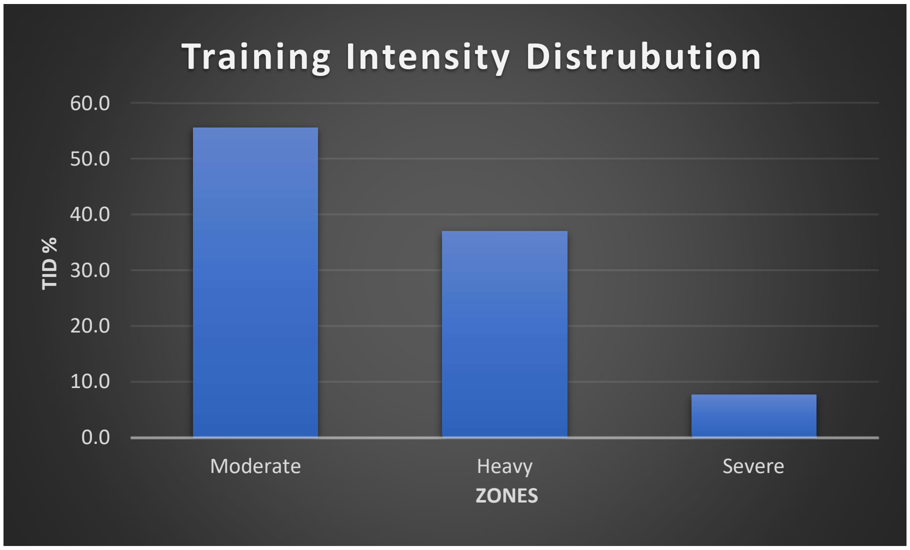

Figure 4. Percentage of training time spent in each zone.

Table 5. Training intensity distribution model of the final sample, N = 10

Training intensity distribution	Number of subjects
POL/PYR	2
LTM	8

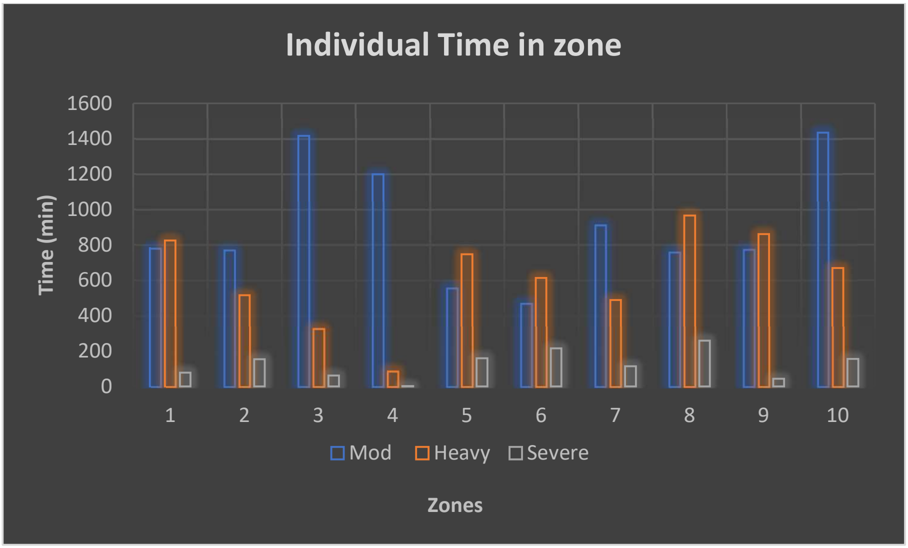

Figure 5. Individual total training time spent in each zone.

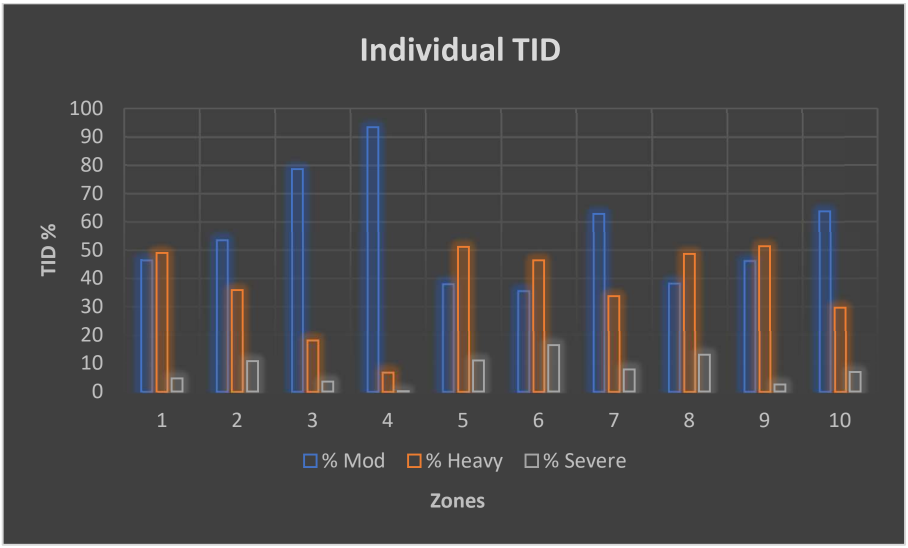

Figure 6. Individual percentage of time spent in each zone.

Correlations between training characteristics/TID and substrate utilisation

A significant positive correlation was found between MFO (g/m) and total training time (TTT) spent in Z1 (r(10) = .657, p = .039), although when expressed as a % of training time (%TT) the relationship was non-significant (r(10) = .512, p = .131). In contrast, there was a significant inverse correlation found between MFO (g/m) and %TT in Z3 (r(10) = -.665, p = .036), although when expressed as TTT the relationship was non-significant (r(10) = -.496, p = .145). No significant relationships between the exercise threshold of VT1 and substrate utilisation were found, although there were trends towards greater MFO, and time spent in Z1 expressed as both TTT and %TT. Additionally, no significant relationships were found between training characteristics and substrate utilisation, although a trend was found towards a larger volume of training and greater MFO. As the exercise threshold VT2 and VO_{2max} are totally dependent upon CHO no correlations were performed, see **Table 6.**

Table 6. Pearson Correlations of training characteristics and intensity distribution with substrate utilisation at FATmax and VT1.

Variable	**FATmax**		**VT1**	
	FAT	**CHO**	**FAT**	**CHO**
Total volume (min)	.431	-.366	.367	-.312
Run volume (min)	.303	-.046	.531	-.352
Bike volume (min)	.278	-.503	-.105	-.036
Time in Z1 (min)	.657*	.116	.492	-.005
Time in Z2 (min)	-.205	-.496	-.160	-.286
Time in Z3 (min)	-.496	-.218	-.166	-.141
% time in Z1	.512	.415	.348	.287
% time in Z2	-.444	-.439	-.346	-.270
% time in Z3	-.665*	-.184	.317	-.146

*P < .05

Correlations between training characteristics/TID and physiological thresholds

Correlations between training characteristics and intensity distribution with HR and PO at physiological thresholds are presented in **Table 7.**

Significant inverse correlations were found between time spent in Z2 expressed as both TTT and %TT, and HR at Fatmax (r(10) =- .691, p = .027), (r(10) = -.674, p = .033). Furthermore, HR at Fatmax was also significantly inversely correlated with time spent in Z3 although only when expressed as TTT (r(10) = -.641, p = .046). In contrast, a significant positive correlation was found between time spent in Z1 when expressed as %TT and HR at Fatmax (r(10) = .697, p = .025), although the relationship was non-significant when expressed as TTT (p = .137). Similarly, HR at VT1 was significantly inversely correlated with time spent in Z2 when expressed as both TTT and %TT respectively (r(10) = -.706, p = .023), (r(10) = -.644, p = .044). Whilst in contrast, HR at VT1 was found to be significantly positively correlated with time spent in Z1 although only when expressed as %TT (r(10) = .657, p = .039). No significant relationships were found between TID and HR at VT2 or VO_{2max}, although similar trends to what was found at Fatmax and VT1 were also found at VT2.

In addition, there were no significant relationships found between TID and PO at any physiological threshold. However, positive trends were found between time spent in Z1 expressed as both TTT and %TT and PO at all physiological thresholds, whereas time spent in Z2 and Z3 expressed as both TTT and %TT were negatively correlated with PO at all physiological thresholds. In regard to training characteristics, no relationships were found with any of the physiological thresholds for both HR and PO.

Table 7. Pearson Correlations between training characteristics and intensity distribution with HR and PO at physiological thresholds.

Variable	**FATmax**		**VT1**		**VT2**		**VO2max**	
	HR	**PO**	**HR**	**PO**	**HR**	**PO**	**HR**	**PO**
Total volume (min)	-.210	-.247	-.358	-.131	.075	.036	-.216	-.111
Run volume (min)	.007	-.121	-.241	-.047	.042	.016	-.205	.022
Bike volume (min)	-.330	-.227	-.245	-.142	.062	.035	-.073	-.198
Time in Z1 (min)	.505	.224	.370	.244	.577	.359	-.052	.166
Time in Z2 (min)	-.691*	-.450	-.706*	-.405	-.462	-.321	-.145	-.275
Time in Z3(min)	-.641*	-.447	-.504	-.133	-.512	-.262	-.072	-.165
% time in Z1	.697*	.472	.657*	.472	.614	.482	.135	.368
% time in Z2	-.674*	-.450	-.644*	-.490	-.549	-.451	-.124	-.351
% time in Z3	-.581	-.452	-.411	-.229	-.549	-.393	-.060	-.261

*P < .05

Discussion

The first key finding of this study was that TID was correlated with FATox at physiological thresholds associated with performance in Ironman distance triathlon, such that greater absolute training time spent in Z1 was positively correlated with MFO at FATmax intensity (r = .657, p = .039), although the relationship was non-significant at VT1 (> .05). Furthermore, the HR intensity at which Fatmax occurred was also positively correlated with relative training time performed in Z1 (r = .697, p = .025). In contrast, greater absolute and relative training time performed in Z2 was negatively correlated with the HR intensity that Fatmax occurred (r = - .691, p = .027), (r = -.674, p = .033), whilst negative correlations were also found with relative training time spent in Z3 for MFO at FATmax (r = -.665, p = .036) and absolute training time spent in Z3 for the intensity at which Fatmax occurred (r= -.641, p = .046). Having said this, the MFO of the athletes participating in the current study was less than the MFO reported by San-Milla´n and Brooks (2017) in both professional endurance athletes and moderately trained individuals (18.2 vs. 39.6 g/min-1) and (18.2 vs. 22.8 g/min-1) respectively. However, the Fatmax in regard to PO of the athletes in the present study was greater than the moderately trained individuals (164 ± 42.3 vs. 132 ± 4.9 W), although considerably less than the PO of professional endurance athletes (238.8 ± 18.2 W) reported by San-Milla´n and Brooks (2017). Additionally, the intensity at which Fatmax occurred in regard to HR was similar to what Michalik, Danek and Zatoń (2021) reported when measuring the FATox rates of male youth road cyclists (120.8 ± 15.2 vs. 124 ± 20 beats · min–1), although significantly more than the (109 ± 15 beats·min−1) that Nikolovski *et al*. (2021) reported when evaluating the FATox of moderately trained male cyclists. The study by Nikolovski *et al*. (2021) additionally compared the FATox at Fatmax with the aerobic threshold/VT1 and found a significant relationship (r = 0.80, p < .05) possibly caused by the increasing rates of glycolysis inhibiting FATox (Jeukendrup and Achten, 2001), although the findings here do not support this.

Hawley, Brouns, and Jeukendrup (1998) explain, endurance training has been observed to result in a number of structural and metabolic adaptations which favour FATox. These adaptive responses include an increase in mitochondrial abundance and function which allows for greater metabolic flexibility that is exhibited in trained endurance athletes through increased FATox during exercise at absolute and relative intensities (San-Milla´n and Brooks, 2017; Smekal *et al* 2003; Rosenkilde *et al* 2015; Philp *et al*., 2021). In light of this, and the reality that FATox is only really present during moderate intensity exercise before declining to zero in the heavy and severe domains where CHO becomes the dominant fuel (Hawley, Brouns, and Jeukendrup, 1998; Peric *et al*., 2022; Nikolovski *et al*., 2021; Knuiman, Hopman and Mensink, 2015), It would seem logical that athletes competing in Ironman distance triathlon where minimising the endogenous CHO cost at competitive intensities is crucial to success should prioritise a large volume of their training in Z1, the moderate domain. The findings of the present study support this, in that a training distribution focusing on accumulating a larger volume of low-intensity training was associated with better FATox. However, despite these findings what was of interest was that the athletes in the present study utilised CHO at a rate of (161.7 ± 31.6 g/hr) at VT1, the intensity suggested to have the greatest relationship with Ironman distance triathlon (Laursen *et al*., 2002). Now considering the data presented in **Table 1**. and the energy demands reported by Barrero, Erola, and Bescós (2014) where a similar subject group to the present study (non-professional male triathletes) consumed an average of 927 ± 178 g of carbohydrates (90% of the overall EI), corresponding to ~84 g/h during an Ironman distance triathlon, it would appear evident that the athletes in the presents study would have depleted their endogenous supply of CHO (350-700g) (Cermak and van Loon, 2013; Maunder, Kilding and Plews, 2018), plus whatever exogenous CHO they consumed during the race (60-90 $g{\cdot}h^{-1}$ /optimal dose 78 $g{\cdot}h^{-1}$) (Cermak and van Loon, 2013) after only 8 hours of racing, thus leading to subsequent fatigue prior to the start of the marathon.

In addition, the findings of the present study also revealed that greater absolute and relative training time performed in Z2 was significantly inversely correlated with HR at VT1 (r = -.706, p = .023), (r = -.644, p = .044), whilst similar trends were also found between HR at VT1 and greater absolute and relative training time performed in Z3, although relationships were non-significant. In contrast, a greater relative training time performed in Z1 had a significant positive correlation with HR at VT1 (r = .657, p = .039). As such, the findings suggest that although high-intensity training (HIT) may lead to rapid adaptions of various tissues and to an increase of aerobic and anaerobic performance in less time compared with other exercise intensities (Gallo *et al*., 2022), performing a large amount of high-intensity volume over several weeks leads to no further adaptations, whilst potentially increasing the risk of overtraining (Kenneally, Casado and Santos-Concejero, 2018). Therefore, Seiler (2010) suggest a relatively low volume of HIT training sessions per week seems to be sufficient for inducing physiological adaptations and performance gains without inducing excessive stress over the long term. The findings within support this, in that no significant relationship between TID and PO were found at any of the physiological thresholds, although it is important to note that trends were found suggesting that a greater proportion of training time spent in Z1 was associated with better PO at all physiological thresholds. Jones and Carter (2000) suggest, endurance can be defined as the capacity to sustain a given velocity or power output for the longest possible time, and with the main goal of triathlon being to finish the competition as quickly as possible (Borrego-Sánchez *et al*., 2021) it may seem intuitive to perform a relatively large percentage of training time at high-intensity.

However, the results here suggest that a TID based on accumulating a relatively large percentage of training time in Z2 and Z3 brings no additional benefits in regard to PO.

As previously discussed, there are two basic patterns of TID present throughout the literature (Seiler, 2010). The traditional LTM where training intensities are organised at or very near the lactate threshold, and models such as POL or PYR where the vast majority of training is spent at low intensity (Muñoz and Varela-Sanz, 2018; Seiler and Kjerland, 2006). Previous research has shown that it is beneficial both for elite and sub-elite endurance athletes to adopt a TID such as POL and PYR where a large percentage of training time is spent in Z1 (Filipas *et al*., 2022; Muñoz and Varela-Sanz, 2018; Sanders, Myers and Akubat, 2017; Kenneally, Casado, and Santos-Concejero, 2018). Seiler and Kjerland (2006) reported the TID of junior male cross-country skiers to be (75%, 8%, 17%), when using the TIZ method. Similarly, both Sanders, Myers and Akubat (2017) and Kenneally *et al*. (2021) reported a TID of (86.8%, 8.8%, 4.4%) and (87.2%, 6.1%, 6.6%) when using TIZ in male competitive road cyclists and world-class middle- and long-distance runners. However, when using a similar subject group to the recreational triathletes found in the present study Neal, Hunter and Galloway (2011) revealed the TID to be (69%, 25%, 6%) in the 6-month period, preceding an Ironman event. More so, the TID during the first phase of training (0-2 months) was (62%, 31%, 7%), somewhat similar to the TID reported in the present study (55.6%, 37%, 7.6%). It is also important to note that the training volume during this phase was 8.1 hrs per week compared to only 6hr 49 min per week in the current study, which may equate for the difference. In addition, a study by Muñoz *et al*. (2014a) involving recreational triathletes preparing for an Ironman event revealed that although all the athletes were prescribed a TID emphasising a large volume of zone 1 training (77%, 20%, 3%), actual TID was reported to be (68%, 28%, 4%). The authors Muñoz *et al*. (2014a) stated the most common deviation from the training prescription was that athletes cycled at higher intensity when they were not supervised by a coach, therefore Z1 training became Z2 training at many times. It is findings such as those reported by Muñoz *et al*. (2014a) that add to the belief that less experienced athletes train too hard during low-intensity sessions and not hard enough during high-intensity sessions, thus leading to a high percentage of training time in zone 2, contrary to the training schedule (Muñoz and Varela-Sanz, 2018; Seiler and Kjerland, 2006; Seiler, 2010). The analysis of the athletes TID in the present study support this notion, in that training time spent in Z1, Z2, and Z3 was (55.6%, 37%, 7.6%) respectively, thus representing a LTM approach. Although the LTM has been demonstrated to show significant improvements among untrained subjects (Seiler and Kjerland, 2006; Cejuela and Sellés-Pérez, 2022; Pérez *et al*., 2020), when Esteve-Lanao *et al.* (2007) compared the LTM (66.8%, 24.7%, 8.5%) to POL (80.5%, 11.8%, 8.3%) using sub-elite endurance runners the magnitude of the improvement in running performance during a 10km cross country race was significantly greater (p = 0.03) for the POL group (-157 13s vs. -121.5 ± 7.1s). More so, the study by Muñoz *et al*. (2014a) revealed performance time during an Ironman had a significant inverse correlation with both total training time and training time in zone 1 (r = –.69) and (r= –.92) respectively, whereas in contrast a moderate positive correlation and a strong positive correlation were found between total training time in zone 2 and percentage of total training time in zone 2 and performance time in competition (r = .53) and (r = .94) respectively.

In addition to the similarities in results found in the present study and those reported by Muñoz *et al*. (2014a), both studies also used the TIZ approach to quantifying TID. This approach registers all HRs from the start to the finish of every training session without considering the nature of the training sessions performed (Seiler and Kjerland, 2006). The strength of this approach is that every training minute is incorporated into the quantification (Sylta, Tønnessen, and Seiler, 2014). However, a weakness of this approach may be that the impact of high-intensity sessions, such as interval training are diluted by the considerable zone 1 and 2 HR contribution to even a very hard high-intensity interval session (warm-up, recovery between intervals, cool down) (Esteve-Lanao *et al.*, 2007; Sylta, Tønnessen, and Seiler, 2014). Therefore, the TIZ approach may underestimate the energetic and sympathetic stress of repeated high-intensity bouts such as interval training (Seiler and Kjerland, 2006). With this in mind Bellinger, Arnold and Minahan (2019) compared the TID of a group of highly trained middle-distance runners over a 8-week period using 3 different methods of training-intensity quantification which included continuous running speed, HR monitoring, and RPE. The results showed that a TID based on RPE (39.6%, 31.9%, 28.5%) provided significantly greater training time in Z2 and Z3 compared with a TID based on HR (79.6%, 17.0%, 3.4%) (P < .001) and running speed (79.9%, 5.3%, 14.7%) (P < .001). Furthermore, in regard to HR greater training time was spent in Z2 (−1.64 ± 0.53; P < .001) and less in Z3 (−1.59 ± 0.51; P < .001) when compared to running speed, despite both methods producing similar training time in Z1. In addition, Sanders, Myers and Akubat (2017) investigated subjective and objective measures of TID quantification in male competitive road cyclists and revealed similar results, in that a TID based on RPE (44.9%, 29.9%, 25.2%) provided moderate to very large differences compared with TID quantified using methods based on time spent in predefined HR (86.8%, 8.8%, 4.4%), or PO (79.5%, 9.0%, 11.5%) zones. Sanders, Myers and Akubat (2017) suggest the reason for this may be partly explained by the fact that RPE is a categorization of the entire training session, whereas HR and external measures of training intensity distributions are based on minute-by-minute data of the training session, thus the duration rather than intensity of training may influence the RPE. Therefore, it is suggested the use of RPE as a measure of training intensity may be less than optimal, although when used in conjunction with objective measures, RPE may provide additional insights into the athletes' fatigue state

(Sanders, Myers and Akubat, 2017; Bellinger, Arnold and Minahan, 2019). Having said this, objective measures such as HR, PO, and running speed in the aforementioned studies (Sanders, Myers and Akubat, 2017; Bellinger, Arnold and Minahan, 2019) also showed differences in Z2 and Z3, although training time in Z1 was similar. The greater accumulation of training time in Z2 associated with a TID based on HR is explained by the "physiological lag" inherent with HR, while external measures such as PO and running speed provide a more direct and immediate measure of exercise intensity (Seiler, 2010; Sanders, Myers and Akubat, 2017; Bellinger, Arnold and Minahan, 2019**;** Sylta, Tønnessen, and Seiler, 2014). As such the intensity distributions of HR may not reflect the neuromuscular demand of high-intensity sessions which may lead to even greater differences in TID at competitive stages of the season when training load is high (Sanders, Myers and Akubat, 2017). Considering this, a systematic review by Kenneally, Casado and Santos-Concejero (2018) suggest an alternative approach to organise TID is one based on race pace. The race-pace-based approach recognizes the traditional high volume of low-intensity training associated with endurance performance, but in-turn organises high-intensity training into zones based on a percentage of race pace, thus applying the key training principle of specificity (Kenneally, Casado and Santos-Concejero, 2018; Muñoz *et al*., 2014a). However, it is important to mention that although the race-pace approach is readily employed by endurance runners and coaches, caution is needed when applying it to multi-sport disciplines such as Ironman triathlon as these events do not share the same capacity for direct competition to competition comparison of pace (Kenneally, Casado and Santos-Concejero, 2018).

Taken together, it is evident that the method of training-intensity quantification largely effects the computation of the TID. As such, the TID of the athletes in the present study (55.6%, 37%, 7.6%) that represented the LTM may have possibly underestimated a significant amount of high-intensity training performed. As previously mentioned, considering the lack of time and resources available for most recreational athletes (Rosenblat, Perrotta, and Vicenzino, 2019; Pérez *et al*., 2020) it is reasonable to assume that the athletes in the present study would have adopted the session-goal approach to quantify high-intensity training, which assigns an entire training session to 1 of the 3 HR zones based on the predominant goal of that session (Sylta, Tønnessen, and Seiler, 2014). However, when these same sessions were later quantified for analysis using a TIZ approach the physiological lag inherent with HR would of considerably underestimated training time spent in Z3. As such, Sylta, Tønnessen, and Seiler (2014) suggest a useful conversion factor between TIZ, and session goal approaches is to multiply TIZ estimates of high-intensity session by 3 to give the equivalent distribution based on the session goal approach. Therefore, it could be speculated that a more realistic TID of the athletes participating in the present study may have represented a slightly more polarised distribution with a relatively larger percentage of training time spent in Z3.

However, despite the possible errors associated with the TIZ method it is important to mention that when analysed individually two of the participants in the present study who were observed to be utilising a TID with a relatively large volume of Z1 training (86%, 12.5%, 1.5%) also possessed greater MFO when compared to the other eight remaining participants (24.5 ± 2.2g/min vs. 16.6 ± 5.4g/min) who were observed to be utilising a TID with a relatively large volume of training performed in Z2 (48.1%, 43.3%, 9.25%). Furthermore, these two participants categorised as POL/PYR in the present study also possessed far greater PO at Fatmax when compared to the remaining participants categorised as LTM (212.5 ± 53 W vs. 151.9 ± 32.5 W) which was more in line with the PO of professional endurance athletes (238.8 ± 18.2 W) reported by San-Milla´n and Brooks (2017).

With all things considered, the findings of the present study add to the belief that recreational athletes may possibly be working too hard. Although the LTM is considered effective for recreational athletes with limited time and experience (Pérez *et al*., 2020; Muñoz and Varela-Sanz, 2018) the results within suggest that even with less than 7 hours per week to train a TID based on a high volume of training time in Z1 and reduced volumes in Z2 and Z3 may allow for improved performance variables associated with ultra endurance triathlon (Filipas *et al*., 2022; Muñoz and Varela-Sanz 2018; Neal, Hunter and Galloway, 2011). More so, as the study also revealed the potential CHO deficit Ironman triathletes face during competition, it is suggested that a TID with a relatively large volume of Z1 will also enhance metabolic flexibility (Achten and Jeukendrup, 2003), thus delaying fatigue associated with the depletion of endogenous CHO (Maunder, Kilding and Plews, 2018).

Strengths and Limitations

To the best of the authors knowledge, this is the first study to describe the TID of well-trained male triathletes in relation to physiological and performance variables associated with Ironman distance triathlon performance. Furthermore, in light of the relative success of the specific testing protocol designed to determine Fatmax and VO_{2max} during the same test, it is suggested that this protocol may be of merit to future studies using a similar subject group for logistical and practical reasons. However, the present study acknowledges the potential shortcoming of the TIZ quantification approach utilised within, in that a significant amount of high-intensity training may not have been accounted for due to the physiological lag inherent with HR (Seiler and Kjerland, 2006). Furthermore, as the present study focused only on the general preparation phase of the season, it seems reasonable to assume that changes in TID may occur at different phases of the season and prior to important competitions (Filipas *et al.,* 2022; Bellinger, Arnold and Minahan, 2019). Finally, as the participants of the present study were all well-trained male recreational athletes, the findings may not be applicable to female populations or athletes of different levels (Maunder, Kilding and Plews, 2018).

Practical applications

As discrepancies observed between methods of measuring TID may have implications for the evaluation and future prescription of training sessions (Sanders, Myers and Akubat, 2017; Bellinger, Arnold and Minahan, 2019), it is suggested an approach based on physiological and performance measures may allow for a more consistent and logical analysis. Therefore, an approach whereby the athlete combines the use of HR to organise low intensity training, whilst sessions involving HIT intervals and frequent changes of power or running speed are organised by external measures. Furthermore, as Ironman triathletes are likely to periodize their TID during different training phases (Bellinger, Arnold and Minahan, 2019), it is suggested that during the off season and general preparation phase athletes utilise TID's such as POL and PYR to build volume whilst avoiding over training (Seiler and Kjerland, 2006). Whereas, when entering the specific preparation and competition phases of the season the training should become more specific to the pace of the event (Kenneally, Casado and Santos-Concejero, 2018), therefore athletes may then opt for the race-paced approach with the TID representing somewhat more of a LTM.

Conclusion

Given the number of variables associated with the assessment of TID in recreational triathletes (Suriano and Bishop, 2010), it is not easy to draw conclusions as to the effectiveness of the training intensity on the key measures of adaptation associated with Ironman distance triathlon. However, the findings within do support the consensus that a TID with a relatively large volume of Z1 training seems superior when compared to a TID prioritising a relatively large volume of training in Z2 (Rosenblat, Perrotta and Vicenzino, 2019; Filipas *et al.*, 2022; Muñoz and Varela-Sanz, 2018). Nevertheless, future research is needed to focus on experimental manipulation of TID at different phases of the season, and also the methods used to measure TID, thus improve our understanding of its impact on the training-induced adaptations in ultra-endurance triathletes.

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Appendix

Appendix 1.

Item	Make & Model	Reference	Website
Stadiometer	Seca 213	(Seca, Hamburg, Germany)	https://www.seca.com
Seca Weighing Scale	Seca 875	(Seca, Hamburg, Germany)	https://www.seca.com
Wattbike Atom	Wattbike atom x	(Wattbike, Nottingham, UK)	https://www.wattbike.com
Metabolic Cart	Coretex Metalyzer 3B	(Leipzig,Germany)	https://cortex-medical.com
Calibration gas	Cranlea 995/2619 (20% O2, 8% CO2)	(Cranlea, Birmingham, UK)	https://www.cranlea.co.uk
Heart rate chest strap	Polar H10	(Polar Electro, Warwick, UK)	https://www.polar.com/uk-en
Mouthpiece	Hans Rudolph 2700 series large 2-way non-return breathable valve	(Hans Rudolph, Kansas, USA)	https://www.rudolphkc.com