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TRIATHLON PERFORMANCE: PHYSIOLOGICAL AND TRAINING STRATEGIES FROM SUPER SPRINT TO LONG DISTANCE EVENTS

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ABSTRACT

Triathlon is an endurance sport that combines swimming, cycling, and running across varied race distances, each imposing unique physiological and tactical demands. This article examines the distinct demands of triathlon race formats and offers insights into optimized training and periodization strategies for different distances, from super-sprint to long distance. Key physiological determinants such as VO_2max, lactate threshold, efficiency, and durability play critical roles in endurance performance, with the relative importance of each factor varying by distance. Shorter races necessitate high-intensity work and quick bursts of anaerobic power, while longer events rely heavily on aerobic efficiency and durability to maintain performance over time. The article contrasts traditional and block periodization methods, emphasizing the advantages of block periodization for short-distance athletes. Additionally, training intensity distribution models, such as pyramidal and polarized, are explored, highlighting their applications to both short- and long-distance training needs. Finally, season scheduling and competition preparation are discussed, including the significance of tapering for peak performance. Together, these insights provide a framework for structuring effective training and competition schedules tailored to different triathlon distances.

Key words: triathlon, endurance training, periodization, physiology

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INTRODUCTION

Triathlon is a multifaceted endurance sport that blends swimming, cycling, and running, being each discipline connected by a brief transition area where the athlete changes between disciplines (swim to cycle, cycle to run), before continuing the race. According to World Triathlon, the first recorded triathlon took place in San Diego, USA, in 1974s. Since then, its popularity grew rapidly and became one of the fastest growing sports all over the world, making its debut in the 2000 Olympic Games (Sidney), as well as expanding into a variety of different events (Espejo et al., 2024).

TRIATHLON DISTANCES AND RACE FORMATS

Triathlon events are distinguished primarily by their distances, and each format offers its unique set of challenges. On one hand, there are the ‘draft-legal’ formats, which includes super sprint (250–300m swim, 5–8km bike, and 1.5–2km run), sprint (750m swim, 20km bike, 5km run), and Olympic or ‘standard’ distance (1,500m swim, 40km bike, 10km run). Super-sprint distance is usually raced in team mixed–relay format (2 women, 2 men, alternatively), with its Olympic debut in Tokyo 2020, meanwhile sprint and standard distances are competed individually (Martínez-Sobrino et al., 2024). On the other hand, ‘non draft-legal’ races, where athletes have to maintain at least 12m long between them to reduce the benefits of drafting, comprehend middle (1,900-2,999m swim, 80–90km bike, 20–21km run) and long distance (3,000–4,000m swim, 91–200km bike, 22–42.2km run) races, being the most popular distances 1,900m–90km–21km and 3,800m–180km–42.2km respectively (Bevins et al., 2024). A summary of triathlon distances can be seen in Table 1.

Table 1. *Triathlon distances based on World Triathlon rules*

Distance	Swim (m)	Bike (km)	Run (km)
Super Sprint[1]	250 – 300	5 – 8	1.5 – 2
Sprint	750	20	5
Olympic/Standard	1,500	40	10
Middle	1,900 – 2,999	80 – 90	20 – 21
Long	3,000 – 4,000	91 – 200	22 – 42.2

[1]Mixed relay

PHYSIOLOGICAL DEMANDS

Physiological determinants of endurance performance have been previously described (Joyner & Coyle, 2008), influencing how fast an athlete can move at a sustainable level of effort over a prolonged period:

- *Maximal oxygen consumption ($\dot{V}O_2max$):* This is the maximum rate at which an individual can consume oxygen during intense exercise. It reflects the integrative ability of the cardiovascular system to deliver oxygen to the working muscles. Elite endurance athletes typically exhibit very high $\dot{V}O_2$max values (70-85 ml·kg·min^{-1}), which are closely tied to factors like cardiac output, blood flow, and oxygen extraction by muscles (Lopes et al., 2012).

- *Lactate threshold:* This is the exercise intensity at which lactate begins to accumulate in the blood. It is considered one of the best predictors of endurance performance. Trained athletes can sustain exercise at higher percentages of their $\dot{V}O_2max$ before reaching their lactate threshold, allowing them to maintain a high pace for extended periods. The lactate threshold reflects the oxidative capacity of muscles and is an important factor in how long athletes can sustain near-maximal effort (Lopes et al., 2012).
- *Efficiency:* It refers to the oxygen cost required to sustain a given pace or power output. Better efficiency allows athletes to perform at higher speeds with less oxygen consumption. Efficiency varies greatly between individuals and although it is influenced by factors like muscle fiber type and mechanical work, its precise determinants, especially in running, remain somewhat unclear (O'toole et al., 1989).

In addition to these tree factors, *durability* has been proposed to be the fourth key determinant of endurance performance. Durability refers to an athlete's ability to maintain their physiological attributes (such as efficiency, threshold, and capacity for oxygen use) over prolonged exercise without significant deterioration. During long events, fatigue leads to reductions in muscle efficiency, fuel utilization, and cardiovascular response, which compromise performance. Durability defines how long and to what extent an athlete can sustain their physiological potential under these conditions. Essentially, athletes with higher durability experience less decline in their physiological functions, allowing them to maintain a faster pace or higher power output for longer periods of time (Maunder et al., 2021).

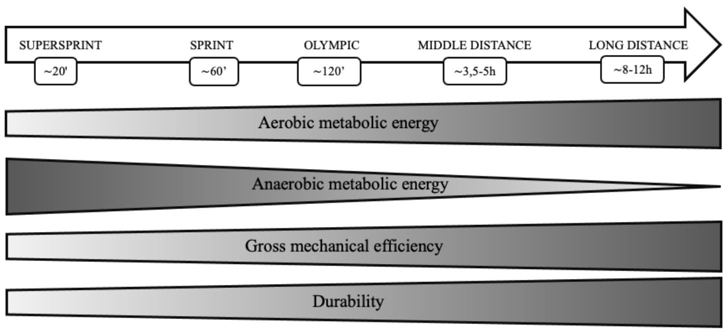
Regarding triathlon, for shorter events like the super sprint, sprint, and standard distance, the physiological demands include a significant reliance on anaerobic metabolism (Figure 1). Athletes in these races are required to generate quick bursts of power, particularly during fast starts, high-intensity intervals on the bike, or swift transitions. Drafting in draft-legal formats such as sprint and Olympic distances further influences the physiological requirements. Drafting can reduce the oxygen demand, especially in the cycling segment, allowing athletes to conserve energy by lowering overall exertion while maintaining high speeds. This energy savings can then be strategically used to increase running pace or intensity toward the race's end (Sharma & Périard, 2020).

In contrast, as race distances extend to middle-and long-distance formats, the aerobic system becomes increasingly dominant, while reliance on anaerobic energy pathways markedly decreases (Figure 1). These longer events necessitate sustained energy output primarily through aerobic metabolism, with an increasing reliance on fat oxidation as the event progresses. Unlike shorter races where glycogen is the primary fuel source, in long-distance triathlons, energy shifts gradually toward fat stores, with lipid oxidation potentially accounting for up to 80% of the total caloric expenditure as the race continues. This shift highlights the need for extensive endurance training aimed at improving the body's efficiency in mobilizing and utilizing fat stores, as well as strategies to manage limited glycogen reserves (Sharma & Périard, 2020).

Race pacing also diverges by distance. Shorter races are characterized by positive pacing strategies—athletes push hard initially to secure a competitive position. This approach increases the anaerobic load but enables faster starts and higher overall intensities in the limited time. Longer formats, however, favor an even pacing strategy, reducing the physiological cost of early effort to conserve energy. This pacing conserves glycogen and mitigates the neuromuscular fatigue that can impair performance in the later stages of a long-distance event (Maunder et al., 2021).

Finally, durability becomes a critical factor in long-distance events. Extended race durations expose athletes to progressive fatigue, impacting fuel utilization and cardiovascular efficiency. Athletes with high durability demonstrate an enhanced capacity to maintain their physiological potential, experiencing slower declines in muscle efficiency and cardiovascular function over time, which allows them to sustain a steady, high power output. This resilience against fatigue and physiological decline is often what differentiates top performers in ultra-endurance events (Mølmen et al., 2019).

Figure 1. *Physiological demands of different distance triathlon events*



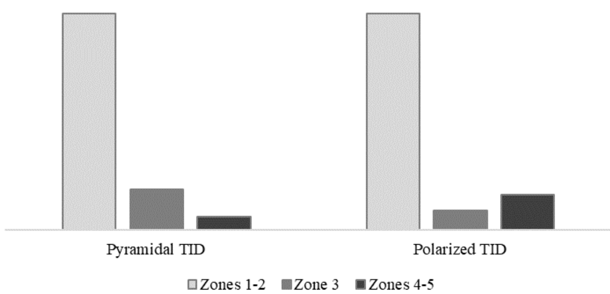
PERIODIZATION AND TRAINING INTENSITY DISTRIBUTION

Effective training for triathlon requires careful planning, with periodization playing a central role. Periodization is the process of dividing the training season into specific phases, each with its own goals and training priorities. In traditional periodization, training phases gradually build multiple attributes—like endurance, strength, and speed—simultaneously over a long preparatory phase, shifting to more intense, race-specific efforts closer to competition. While this approach promotes steady improvement, it can lead to conflicting adaptations and fatigue as various goals are trained concurrently. Block periodization, however, uses shorter, focused blocks (typically 2-4 weeks) dedicated to specific attributes one at a time, allowing for concentrated adaptations without competing demands (Mølmen et al., 2019).

Training intensity is commonly divided into zones based on heart rate, perceived exertion, speed/pace or power output. In a 5-zone model, low-intensity training (zones 1 and 2) builds aerobic capacity and aids recovery from harder efforts, while moderate intensity (zones 3 and 4) improves lactate threshold. High-intensity training (zone 5) develops maximal aerobic power and speed, which is more emphasized in short-distance events (Seiler & Tønnessen, 2009). Therefore, shorter distances benefit from more high-intensity work, whereas long-distance training demands a higher volume of low-intensity training, especially to delay fatigue in extended events.

Regarding training intensity distribution (TID), both pyramidal and polarized TID models have been studied extensively in endurance sports. Pyramidal TID model accumulates more volume in zone 3 than in zones 4-5 and polarized TID accumulates more volume in zones 4-5 than in zone 3 (5-zone model) (Figure 2) (Stöggl & Sperlich, 2015). Cejuela and Selles-Perez (2023) found that short-distance triathletes often benefit from first 10-11 weeks of pyramidal TID, with a polarized TID from week 11-12 aiming to peak performance in major competitions. In the case of middle- and long-distance triathletes, a pyramidal TID may be a more effective and successful approach, as it allocates a large proportion of training time in low (zones 1-2) and moderate efforts (zone 3) with less amount of time at zones 4-5, which would be more specific to race demands (Dasa et al., 2024).

Figure 2. *Training intensity distribution models in a 5-zones model*



SEASON SCHEDULING AND COMPETITION PREPARATION

Season scheduling is also a vital part of a triathlete's preparation, especially in balancing peak performance across a racing season. For short-distance triathletes, who may have multiple peaks during the season, the preparatory phase focuses on enhancing aerobic base, followed by targeted high-intensity block phase aimed to reach optimal performance for key races, like World Triathlon Series events (Cejuela & Selles-Perez, 2023). These athletes may plan their season around multiple national and international races, building and tapering between them to maintain peak performance capabilities.

In contrast, middle- and long-distance triathletes often schedule fewer peak events, usually one or two major competitions per season. Their preparatory phase can last several months, gradually building volume and intensity to reach peak fitness, followed by longer tapering periods to ensure full recovery and optimization of endurance performance (Hausswirth & Lehénaff, 2001).

Tapering, the reduction of training load leading up to a race, is essential for both short- and long-distance triathletes. This period, lasting between 1-3 weeks, involves lowering training volume but maintaining intensity, allowing for recovery while retaining fitness adaptations from the preparatory phase. Short-distance athletes may use slightly shorter, more intense taper periods, while long-distance athletes benefit from longer and gradual tapers.

CONCLUSION

The diverse demands of triathlon, spanning from super-sprint to long distances, require athletes to optimize training and physiological attributes specific to each race format. While shorter-distance races rely on anaerobic power and high-intensity efforts to handle fast transitions and drafting benefits, middle- and long-distance events demand endurance, aerobic efficiency, and durability to sustain prolonged exertion. Block periodization emerges as an effective training strategy for short-distance athletes. Additionally, tailored training intensity distribution, such as pyramidal and polarized models for short-distance and pyramidal for middle and long-distance, aligns well with the distinct physiological requirements of each race type. Strategic season planning and tapering further enhance athletes' readiness, enabling peak performances for targeted events. This approach not only supports athletes' development but also maximizes competitive outcomes across varied race distances.

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