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Training characteristics and performance of two male elite short-distance triathletes: From junior to "world-class"

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Abstract

Objective: The sports-science literature lacks data on training and performance characteristics of international elite athletes over multiple seasons. The present case study provided general training characteristics and performance data of two male short-distance triathletes in the Junior, U23, and international Elite categories.

Methods: General training and performance data of two male elite triathletes were described in swimming, cycling, and running segments from the 2015 to 2022 season. The training load was presented using the ECO model while the training intensity distribution (TID) was a triphasic model.

Results: Both triathletes increased their performance throughout the seasons. Triathlete A increased his VO_{2max} in cycling by 20.6%, in running by 16.7%. His power at VO_{2max} and his speed at VO_{2max} by 18.9% and 11.0%, respectively. Triathlete B improved his VO_{2max} by 17.8% in cycling, by 16.1% in running and his power at VO_{2max} by 24%, and his speed at VO_{2max} by 14.3%. The triathletes trained on average 14–17 h a week. The TID model was polarized.

Conclusions: To achieve the top international level, it is necessary to consider the following measures: training load progression; improvements in physiological variables; and participation in international events starting from youth categories.

KEYWORDS

elite athletes, endurance training, long-term development, physiological variables, training intensity distribution, training load, training periodization, triathlon

1 | INTRODUCTION

Before competing in international elite sports events, it is necessary to complete a period of continuous intensive training to achieve high specialization.[1] Differences in peak performance age depend on the sport. Thus, average peak performance age of world-class swimmers is 22 years.[2] In athletics, peak performance age would be between 25 and 27 years in 5000 m and 10 000 m track events, and between 28 and 29 years in marathon distance.[3] In short-distance triathlon, some studies indicate that peak performance is reached at around 27 years in both males and females.[4,5] These data reinforce the fact that systematic training over several seasons is needed to compete at the highest level in any endurance sport.

International competitions are organized differently according to each sport. In the specific case of triathlon, the top races—apart from the Olympic Games—are the world triathlon series (WTS), which are organized by International Triathlon Union (ITU). A good position in the world ranking is usually necessary to access the WTS start lists (only 55 triathletes compete in each WTS). Consequently, points must be obtained in less important events, such as world cups (WC) and continental cups (CC) to improve world ranking positions. Most WTS, WCs, and CCs are short-distance triathlons (sprint and Olympic distance). Taking the recent classification by McKay et al.[6] as a reference, one criteria to reach Tier 5 (world-class) would be to form part of the top 3 at a major international event. Only 6–8 WTSs are organized each season and any triathlete who gets a podium in a WTS should be considered as a "world-class" athlete.[6]

Moreover, there is a growing interest in the sports literature in studies on successful training plans for top endurance athletes.[7–10] In this way, recent training data publications include three top 5 Giro d'Italia cyclists[7]; the training preparation data for the Tokyo 2020 Olympic Games of a world-class triathlete[9]; the training intensity distribution in world-class middle- and long-distance runners[11]; and a finalist's training characteristics in the 5000 m world championships.[10] Aspects such as training volume, periodization, or taper strategies have been presented in these studies. This data is valuable as it is usually difficult to conduct studies with top-performance athletes. Moreover, these studies can help design future elite athlete training programs.

Training periodization is the cyclic ordering of training exercises following specificity, volume, and intensity principles, to achieve peak performance in major competitions.[12] Traditional periodization is commonly used in endurance sports. The periodization model aims to build an aerobic base at the beginning of the season over a period of high-volume low-intensity training. The amount of high-intensity training then gradually increases and the training volume is reduced as the competition date approaches.[12] Several studies, however, have analyzed the effects of alternative periodizations, such as reverse or block periodization, and obtained similar or even superior results in endurance athlete performance.[13–18]

For its part, training intensity distribution (TID) has attracted great interest in the last decade in the field of endurance sports. TID is defined as the time an athlete spends on an exercise across three different training intensity zones[19]: zone 1, at or below the first ventilatory threshold (<VT1); zone 2, between the first and second ventilatory threshold (VT1-VT2); zone 3, at or beyond the second ventilatory threshold (>VT2).[20] Polarized and Pyramidal models have been described as the optimal TIDs to enhance the performance of endurance athletes.[19,21–23] Both models are characterized by the accumulation of a high percentage of training volume in zone 1, but the Polarized model accumulates more volume in zone 3 than in zone 2, and the Pyramidal model accumulates more volume in zone 2 than in zone 3.[24] Nevertheless, a fewer number of studies have analyzed training load using specific training load quantification methods for endurance sports.[25,26]

Researchers and coaches in endurance sports are also interested in the physiological and performance data of elite athletes.[27] In this line, several studies on the power profile of high-level cyclists have been recently published.[28,29] Yet descriptive studies on training and physiological adaptations over several seasons are less common. In fact, a recent systematic review concluded that there is an urgent need for additional long-term studies based on the systematic monitoring of athletes from a young age.[30] Therefore, the aim of this case study was to show how an international elite level was achieved by describing the training characteristics together with the physiological and performance data of two male short-distance triathletes over several seasons.

2 | METHODS

2.1 | Participants

This case report focuses on two professional elite triathletes (Triathlete A and Triathlete B) who were born in 1996. They can currently be classified as "world-class" according to McKay's framework for research in sports science.[6] Data for Triathlete A covered seasons 2015–2022, while Triathlete B data covered seasons 2017–2021. During those years, both triathletes trained in the same training group. Some Triathlete B training data were completed for seasons 2015, 2016, and 2022 using his personal training logs but not all the information of these seasons could be shown. All procedures used in this study were approved by the Alicante University Ethics Committee (UA-2017-04-11 expedient). The athletes gave their consent for their data to be published in this study.

2.2 | Physiological testing, anthropometric measures, and training zones setting

Swimming training zones were determined based on speeds associated with different blood lactate concentrations and/or specific times to swim a distance after an incremental swimming test (7×200c/5′). Running and cycling training zones were determined after performing volitional exhaustion incremental tests using a portable gas-exchange analyzer (Cosmed® K4 2). A ramp protocol was used to cycle on a roller, starting at 150 W and increasing 5 watts (W) every 12 s.[31] Triathletes used their own bike and their power meter (ROTOR®). The running test was performed on a 400 m homologated track. Triathletes started at 13.9 km/h and increased 0.3 km/h every 200 m.[32] Training intensity zones were calculated based on ventilatory thresholds (VT) and maximum oxygen consumption (VO_{2max}). The Davis criteria were used to establish these physiological markers.[33] The following variables were measured during the test: oxygen uptake (VO_2); pulmonary ventilation (VE); ventilatory equivalent for oxygen (VE/VO_2); ventilatory equivalent for carbon dioxide (VE/VCO_2); and end-tidal partial pressure of oxygen ($P_{ET}O_2$) and carbon dioxide ($P_{ET}CO_2$). VO_{2max} recorded the highest VO_2 value obtained for any continuous 1 min period. VT1 was determined based on an increase in both VE/VO_2 and $P_{ET}O_2$ with no increase in VE/VCO_2, whereas VT2 was determined based on an increase in both VE/VO_2 and VE/VCO_2 and a decrease in $P_{ET}CO_2$.[33] The heart rate was continuously monitored during the test using radio telemetry (Polar Electro®). Training zones corresponding to swimming were calculated using the individual lactate threshold (ILT), that is, the first inflection point in the lactate-work rate curve, and the onset of blood lactate accumulation (OBLA), which represents the maximal workload of steady-state lactate concentration. OBLA corresponds to the transition from a tolerable workload to a greater intensity.[34–36] The speed of the last repetition of the swimming test was taken as a reference for maximum aerobic speed (MAS).[37]

A total of 8 training zones were used during the workouts to indicate intensity and to calculate the training load. These training zones reported both internal load (HR) and external load (speed or power) data. Moreover, a RPE scale (1–10) was related to these training zones. However, to establish training intensity distribution (TID), three training zones were mainly used: zone 1 (at or below VT1/ILT), zone 2 (between VT1/ILT and VT2/OBLA), and zone 3 (at or beyond VT2/OBLA).[20] The Polarization index was also calculated to quantify the polarization level.[38] This index summarizes the nature of the TID in a single variable. For a polarization index <2.00 AU, the TID was defined as "polarized", while for a polarization index ≤2.00 AU, the TID was defined as "non-polarized".

Anthropometric measurements were performed following standard protocols adopted by the International Society for the advancement of Kinanthropometry (ISAK)[39] by the same anthropometrist with ISAK certification level 3. The thickness of 6 skinfolds (subscapular, triceps, supraspinal, abdominal, front thigh, and medial calf) were measured using a caliper calibrated to the nearest 0.2 mm (Holtain®). Four girths (relaxed arm, flexed arm, thigh, and calf) were measured using a flexible anthropometric steel tape (Holtain®). The sum of skinfolds was calculated, and muscular mass was estimated using the method of Lee et al.[40]

Both the tests and the anthropometrics were carried out between weeks 12 and 16 of the season (depending on the season) in the following sequence: swimming, cycling, and running tests. At least 48 h were left between the tests and high-intensity training was not performed during this time.

2.3 | Training characteristics and control of the training load

Triathlete A's training data was collected from seasons 2015 to 2022 and Triathlete B's from seasons 2016 to 2021. Both triathletes trained in the same group and with the same coach (RC) over these years. The heart rate (HR) and rate of perceived effort (RPE) were used mainly for low-intensity workouts (zones 1 and 2). Speed and power were used to control moderate and high-intensity workouts (zones 3–8) in running and cycling, respectively. The average pace for the 100 m was used to control moderate and high swimming intensity workouts based on the training intensity zones obtained in the incremental swimming lactate test.

The ECOs methodology (the abbreviation ECO comes from "Equivalentes de Carga Objetivos" in Spanish language) was used to calculate the training load. In short, the ECOs were calculated by multiplying the time (minutes) that the triathlete spent in every training zone (1–8) during the workout using a score value between 1 and 50 (depending on the training zone) and a specific factor of 1.0, 0.75, or 0.5 for running, swimming, or cycling, respectively.[41,42] This methodology seemed the most appropriate for triathlon because it compares different endurance activities, taking into account the different degrees of muscle damage, energy cost, effort densities as well as differences in the ability to maintain technique in the three segments.[41,42] Triathletes were filling a detailed training log with the information recorded in their training devices (GPS, HR monitor, and power meter). Subsequently, a specific software (Allinyourmind Training system®) was used to calculate the ECOs. Furthermore, most of the training workouts were supervised by the coach or an assistant coach (SS).

3 | RESULTS

Table 1 shows some of the triathletes' main results from the 2015 to 2022 season. Both triathletes won international events in youth categories, as well as in national

TABLE 1 Main results of each season by triathlete.

	Triathlete A			Triathlete B		
	Position	**Event**	**Place**	**Position**	**Event**	**Place**
Season 2015	1st	National Junior championship	Pontevedra (Spain)	1st	National Junior championship	Verl (Germany)
	4th	World Junior Championship	Chicago (EEUU)	DNF	World Junior Championship	Chicago (EEUU)
	13th	European Junior Championship	Geneva (Switzerland)	1st	European Junior Championship	Geneva (Switzerland)
Season 2016	15th	National championship	Águilas (Spain)	4th	National championship	Düsseldorf (Germany)
	6th	European Cup	Altafulla (Spain)	36th	European Championships	Lisbon (Portugal)
	8th	African Cup	Larache (Morocco)	31st (debut)	WTS	Hamburg (Germany)
Season 2017	7th	World Cup	Tongyeong (Korea)	8th	European championship	Düsseldorf (Germany)
	32nd	World U23 Championship	Rotterdam (Netherland)	29th	WTS	Yokohama (Japan)
	6th	European U23 Championship	Velence (Nederland)	7th	World Cup	Madrid (Spain)
Season 2018	1st	National Elite championship	A Coruña (Spain)	1st	National Elite championship	Düsseldorf (Germany)
	20th	World U23 Championship	Gold Coast (Australia)	6th	World U23 Championship	Gold Coast (Australia)
	3rd	European Championship	Tartu (Estonia)	12st	World Series	Montreal (Canada)
Season 2019	3rd	World Cup	Madrid (Spain)	2nd	World Cup	Madrid (Spain)
	1st	World U23 Championship	Lausanne (Switzerland)	14th	WTS	Hamburg (Germany)
	47th (Debut)	WTS	Hamburg (Germany)	5th	World Cup	Nur-Sultan (Kazajstan)
Season 2020 (COVID)	3rd	National Elite championship	Pontevedra (Spain)	8th	World Mixed Relay Championships	Hamburg (Germany)
	52nd	WTS	Hamburg (Germany)	12st	WTS	Hamburg (Germany)
	8th	World Cup	Valencia (Spain)	11st	World Cup	Mooloolaba (Australia)
Season 2021	6th	World Cup	Arzachena (Italy)	25th	Gran Final WTS	Edmonton (Canada)
	15th	WTS	Abu Dhabi (UAE)	13st	WTS	Hamburg (Germany)
	2nd	European Championship	Valencia (Spain)	2nd	European Mixed Relay Championship	Kitzbühel (Austria)
Season 2022	14th	WTS	Montreal (Canada)	4th	WTS	Cagliari (Italy)
	3rd	WTS	Hamilton (Bermuda)	3rd	WTS	Leeds (UK)
	20th	WTS Ranking	–	9th	WTS Ranking	–

Abbreviations: DNF, did not finish; U23, under 23 category; WTS, world triathlon series.

elite championships. Triathlete B was more experienced in WTS since he made his debut 2 years before Triathlete A. Both triathletes improved their performance in international competitions, by obtaining better results first at continental cups, then at world cups, and lastly at the WTS. Triathlete A progressed from position 264 in the 2015 world ranking to position 21 in 2022. Triathlete B went from position 373 in the world ranking to number 8. Recently, Triathlete A was ranked 20th and Triathlete B came 9th in the 2022 season WTS ranking.

Table 2 shows the evolution of physiological values (VO_{2max} and the percentage at which VT2 and VT1 are located with respect to VO_{2max} in both running and cycling) and anthropometric variables (weight, Sum of skinfolds, and muscle mass) over the seasons. Triathlete A increased his VO_{2max} from 68.1 to 82.1 mL/kg/min in cycling and from 72.3 to 84.4 mL/kg/min in running. The percentage at which VT2 was located rose from 78.3% to 90.3% in cycling and from 83.5% to 91% in running, while VT1 rose from 61.2% to 71.2% in cycling and from 61.1% to 70.2% in running. Triathlete B increased his VO_{2max} from 69.8 to 82.2 in cycling and from 71.4 to 82.9 mL/kg/min in running. The percentage at which VT2 was located increased from 78.2% to 90.1% in cycling and from 83.6% to 90.1% in running, while VT1 rose from 61.1% to 71% in cycling and from 62.9% to 68.9% in running. Slight improvements could be observed in the anthropometric parameters, such as a decrease in the sum of skinfolds from 35.4 to 29 mm in triathlete A and from 34.5 to 28.6 mm in triathlete B. There were no weight changes, however, throughout the seasons.

Performance markers can be observed from Figures 1–4. Triathlete B experienced higher increases in power values compared to Triathlete A. Higher absolute power values were observed in the last seasons for Triathlete B, even though the performance in W/kg was rather similar in both power at VO_{2max} and in power with respect to ventilatory thresholds since the 2018 season. Similar values were observed for running with respect to the speed at ventilatory thresholds because both triathletes started at a similar performance level and increased this value in parallel. Triathlete B, however, started with a lower speed at VO_{2max} in 2016. This value reached the same level as that of Triathlete A after two seasons. The swimming performance of both triathletes increased throughout the seasons at different rates (MAS, OBLA, and ILT), but Triathlete B performed better than Triathlete A in this segment across all seasons.

Table 3 shows the training characteristics of both triathletes throughout the seasons. Triathlete A's training load increased considerably from seasons 2015 to 2016. The triathletes registered ≈2000 ECOs the weeks of maximum training load and a weekly average training load of 1200–1300 ECOs from 2017 to 2021 seasons. Triathlete A achieved his maximum values of weekly average training load (1454 ECOs) and peak of weekly training load (2246 ECOs) in the season 2022. Approximately a third of the international races in which the triathletes took part between the 2015 and 2019 seasons were in the junior and U23 category. A consolidation in top-level races was observed in the last season since the triathletes participated in almost all the WTS events of the season.

The COVID pandemic conditioned the triathletes' progression both in the training load and in the participation in international races. In this way, a lower average weekly training load was observed in the 2020 season, as well as a reduction in the number of international races in 2020 and 2021. An increase in the percentage of cycling training load could also be observed in the 2020 season since cycling sessions on roller increased during the weeks of lockdown.

A progression in the total number of altitude days was observed throughout the seasons, Triathlete A even performing 4 training camps during the 2022 season.

Figures 5 and 6 show each triathlete's weekly training load during the 2019 season. An equal distribution of the training load can be observed across each of the three segments almost every week. Triathlete B was unable to perform a running training load in week 14 due to a small muscle injury. Triathlete A stopped training for 2 weeks after the world cup in Madrid due to a running accident that caused a serious knee injury. These 2 weeks are not represented in Figure 5 since there was no training load. Both triathletes followed a block periodization model that season. Before the first international competition of the season (week 14 for triathlete A and week 17 for triathlete B), the triathletes performed two accumulation mesocycles, two transmutation mesocycles, and one realization mesocycle, which included the tapering for this competition and a decreasing training load. From that moment on, the triathletes performed specific training blocks of one or two mesocycles to prepare for the next competitive block, which took place every 3–6 weeks. The realization (competitive) block is characterized by a 1 to 3-week taper period (depending on the importance of the competition) during which the training load is reduced to achieve optimal fitness before the competition. A large competitive block takes place at the end of the season in which there is a high concentration of races and a reduction in the training load. Journeys, recovery from previous competitions, and preparations for the next make it difficult to accumulate training loads during these weeks. The season produced notable results such as a podium for both athletes in the Madrid WC, the U23 World Championship for triathlete A, or 14th place in the WTS in Hamburg for triathlete B. Three altitude training camps took place during the season

TABLE 2 Physiological, performance and anthropometric values over the seasons.

	SEASON 2015		SEASON 2016		SEASON 2017		SEASON 2018		SEASON 2019		SEASON 2020		SEASON 2021		SEASON 2022	
	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB
VO_{2max} bike (mL/kg/min)	68.1	–	72.5	69.8	74.1	72.2	76.2	74.3	77.5	75.2	80.4	82.0	81.3	82.2	82.1	–
% VT2 bike	78.3	–	79.5	78.2	82.2	81.3	86.3	84.8	87.1	85.5	89.0	89.4	89.7	90.1	90.3	–
% VT1 bike	61.2	–	62.5	61.1	63.3	62.3	65.1	66.9	67.4	66.6	68.6	68.8	70.0	71.0	71.2	–
VO_{2max} run (mL/kg/min)	72.3	–	75.6	71.4	78.2	74.9	81.3	75.3	82.0	76.2	82.9	79.8	83.4	82.9	84.4	–
% VT2 run	83.5	–	84.9	83.6	86.4	84.7	87.5	87.4	88.0	87.5	88.8	88.9	89.4	90.1	91.0	–
% VT1 run	61.1	–	63.4	62.9	65.0	63.8	66.2	65.6	66.5	67.2	68.6	68.1	70.1	68.9	70.2	–
Weight (kg)	60.6	–	59.6	64.5	60.5	63.8	59.7	64.0	60.6	63.7	61.0	64.0	60.9	64.5	60.3	–
Σ Skinfold (mm)	35.4	–	34.4	34.5	35.2	33.2	30.9	32.3	29.2	32.1	30.0	30.4	28.6	28.6	29.0	–
Muscle mass (kg)	29.4	–	29.0	30.2	29.2	30.5	31.0	30.9	29.0	30.8	29.0	30.6	29.0	30.7	28.8	–

Abbreviations: TA, Triathlete A; TB, Triathlete B; VO_{2max}, maximum oxygen uptake; VT1, first ventilatory threshold; VT2, second ventilatory threshold.

over the following weeks: 21–24 for both triathletes, 29–31 and 34–37 for triathlete A, and 32–34 and 36–39 for triathlete B. A greater training load accumulation can generally be observed over these weeks. In addition, these altitude training camps coincide with the weeks prior to the season's main competitions.

Figures 7 and 8 show the triathletes' training volume (training hours) per week as well as the TID, showing the amount of time spent in zones 1, 2, and 3, respectively. We can observe how the TID of the first 4–5 weeks would be high-volume low-intensity (HVT) since more than 90% of the training volume is carried out in zone 1. Subsequently, a pyramidal model is observed until week 10–11, accumulating more amount of training at moderate intensity (zone 2) than at high intensity (Zone 3). The polarized model predominates from week 12 onwards. Moreover, a reduction in training volume can be observed during the major race weeks, as well as in the weeks prior to them to conduct the taper period.

4 | DISCUSSION

The present case study showed the evolution of two male triathletes until the highest international performance level, a podium in the main triathlon sports competition (WTS). Youth category performance does not seem to be a good predictor of elite-level performance[43]; however, the performance in Junior and U23 categories presents a better correlation with future elite category performance.[43] In this line, both triathletes presented significant achievements at the international level in both Junior and U23 categories.

Even though both triathletes competed in a similar number of international races each season, Triathlete B made an earlier WTS debut than Triathlete A. The different policies of each national federation, as well as the performance of triathletes in each country, may determine an earlier debut in top-level triathlon races.

The triathletes showed increases of ≈20% in VO_{2max} over the seasons. Both triathletes achieved a high VO_{2max} (<80 mL/kg/min) value as reported for other top endurance athletes such as a professional cyclist (87 mL/kg/min), a world-class triathlete (84 mL/kg/min) or elite marathon runners (81.0 ± 4.0).[8,9,44] Both triathletes achieved a relative power value at VO_{2max} and at ventilatory thresholds slightly above that of U23 cyclists but below that of professional cyclists.[29] The speeds achieved at VO_{2max} and at ventilatory thresholds were in line with the data reported for a world-class 5000-m track and field athlete.[10]

Both triathletes reported over 15 h of weekly training in almost each season. This training volume was greater than that reported in other studies on world-class endurance

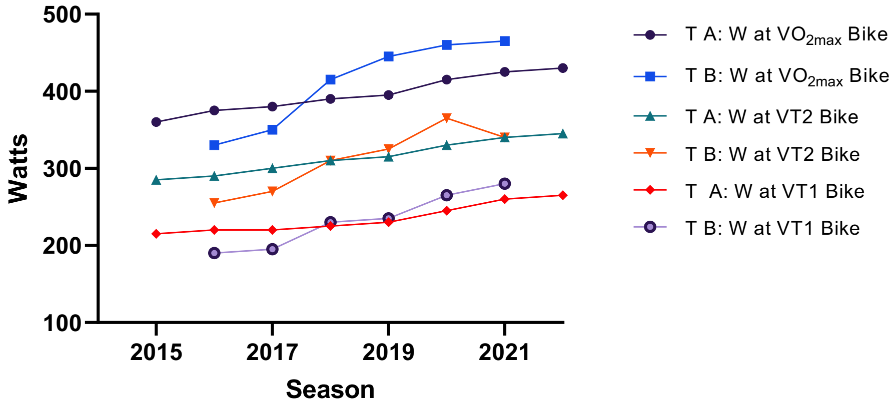

FIGURE 1 Absolute power values of cycling over the seasons. TA, Triathlete A; TB, Triathlete B; VO_{2max}, maximum oxygen uptake; VT1, first ventilatory threshold; VT2, second ventilatory threshold; W, watts.

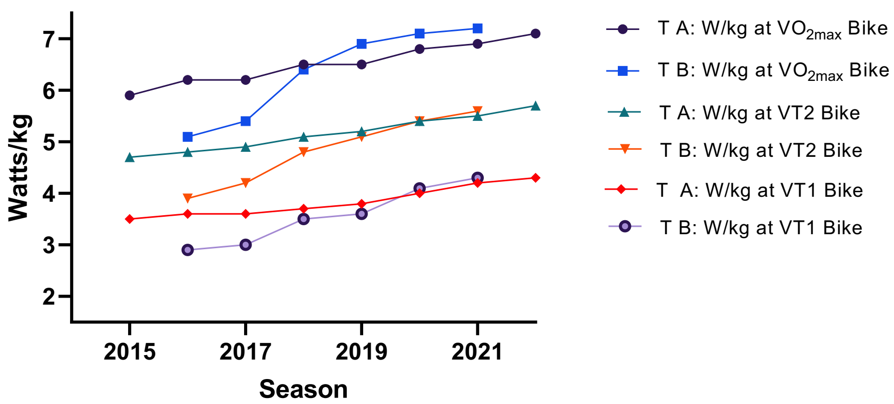

FIGURE 2 Power values relative to body weight of cycling over the seasons. TA, Triathlete A; TB, Triathlete B; VO_{2max}, maximum oxygen uptake; VT1, first ventilatory threshold; VT2, second ventilatory threshold; W, watts; W/kg, watts relative to body weight.

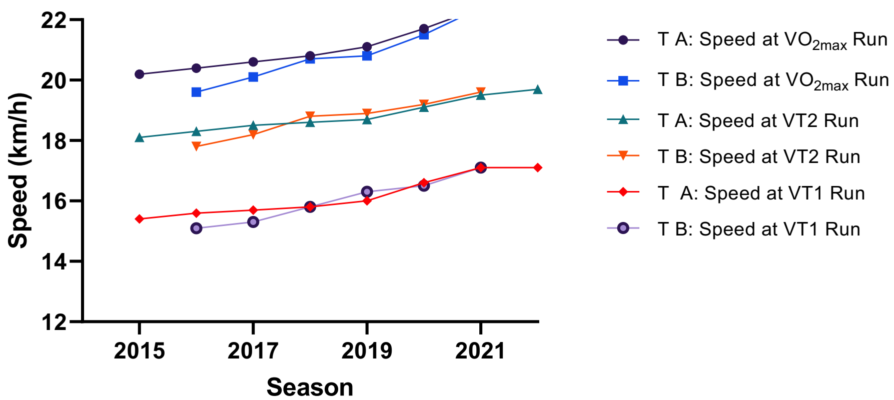

FIGURE 3 Speed values of running over the seasons. TA, Triathlete A; TB, Triathlete B; VO_{2max}, maximum oxygen uptake; VT1, first ventilatory threshold; VT2, second ventilatory threshold.

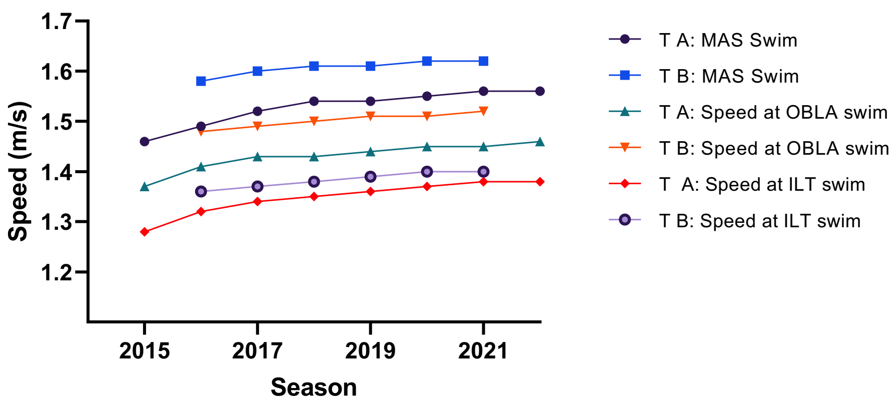

FIGURE 4 Speed values of swimming over the seasons. ILT, individual lactate threshold; MAS, maximum aerobic speed; OBLA, onset of blood lactate accumulation; TA, Triathlete A; TB, Triathlete B.

TABLE 3 Training characteristics over the seasons.

	SEASON 2015		SEASON 2016		SEASON 2017		SEASON 2018		SEASON 2019		SEASON 2020		SEASON 2021		SEASON 2022	
	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB	TA	TB
Training load																
W.A. ECOs	1031	–	1321	–	1332	1197	1190	1188	1257	1237	1290	1296	1363	1206	1454	–
Maximum ECOs week	1625	–	1953	–	2137	2053	1889	2108	1902	2013	1834	1871	1987	1840	2246	–
Minimum ECOs week	388	–	319	–	569	361	415	307	521	586	509	428	627	477	489	–
% ECOs swimming	37.2	–	36.2	–	35.1	34	31	31.6	31.8	30.4	32	29.6	33	31.6	33	–
% ECOs cycling	30.1	–	29	–	29.8	27.7	30.5	30.7	30.3	32.5	32.3	35.5	29.8	31.2	31.5	–
% ECOs running	32.7	–	34.8	–	35.1	38.3	38.5	37.6	37.9	37.1	35.7	34.9	37.2	37.2	35.5	–
% ECOs Z1	58.4	–	54.4	–	50.9	54.9	49.3	50.2	46.1	49.5	45.8	51.1	45.1	49.6	44.6	–
% ECOs Z2	8.4	–	2.8	–	3.5	4.4	4.2	6	4.1	5.8	2.1	5.1	6.3	4.3	8.6	–
% ECOs Z3	33.2	–	42.8	–	45.6	40.7	46.5	43.8	49.8	45.7	52.1	43.8	48.6	46	46.8	–
Training volume																
Weeks (*n*)	43	45	42	47	51	51	49	51	46	45	51	52	50	48	51	52
W.A. training time (*h*)	14.4	15.1	16.7	16.5	16.9	17.2	14.8	16.6	15.6	16.3	14.6	16.3	15.2	15.3	15.8	17.1
Maximum weekly (*h*)	19.1	19.4	25.9	23.3	25.3	29	24.9	25.7	25.6	25.8	25.2	24.2	25.9	23.3	26.8	27.1
Minimum weekly (*h*)	6.9	4.6	4.4	5.7	5.8	8	6.7	5.8	8.4	10.0	5.2	9.2	5.8	8	4	6
% Training time Z1	87	–	89.3	–	86.2	87.8	84.8	85.1	82.1	84	82.8	86.2	81.2	84.7	79	–
% Training time Z2	4.6	–	1.5	–	2.9	3.1	3	4.8	4.5	4.4	2.5	3.8	5.6	3.4	8.3	–
% Training time Z3	8.4	–	9.2	–	10.9	9.1	12.2	10.1	13.4	11.6	14.7	10	13.2	11.9	12.7	–
Polarization index (AU)	2.2	–	2.7	–	2.5	2.4	2.5	2.2	2.4	2.3	2.7	2.3	2.3	2.5	2.1	–
Altitude camps																
Days (*n*)	36	0	21	0	37	36	45	44	54	51	54	35	72	68	98	28
Camps (*n*)	2	0	1	0	2	2	2	2	3	3	3	2	3	3	4	1
Races																
WTS races (*n*)	0	0	0	2	0	2	0	2	4	6	2	2	1	2	7	6
International races (*n*)	6	7	3	9	10	7	13	11	13	11	6	4	6	5	11	11

Abbreviations: ECOs, Equivalentes de Carga Objetivos (Spanish language); *h*, hours; *n*, total season number; W.A, Weekly average; Z, Zone.

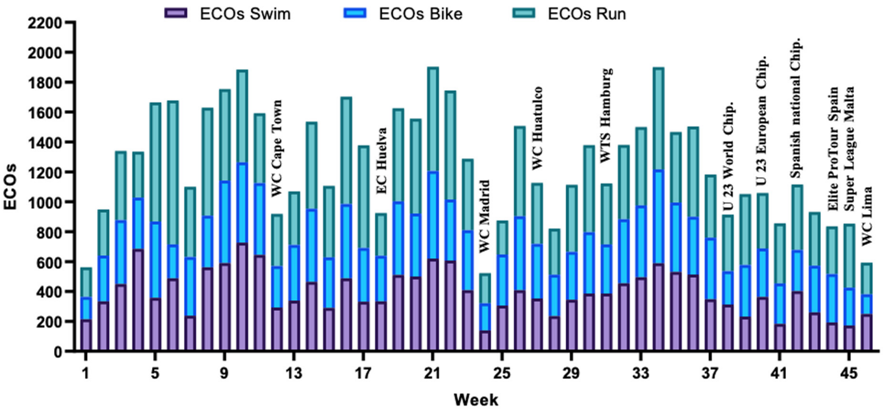

FIGURE 5 Training load (ECOs) by segment of triathlete A in 2019 season. Chip., Championship; ECOs, Equivalentes de Carga Objetivos (Spanish language); EC, European Cup; WC, World Cup; WTS, World triathlon series.

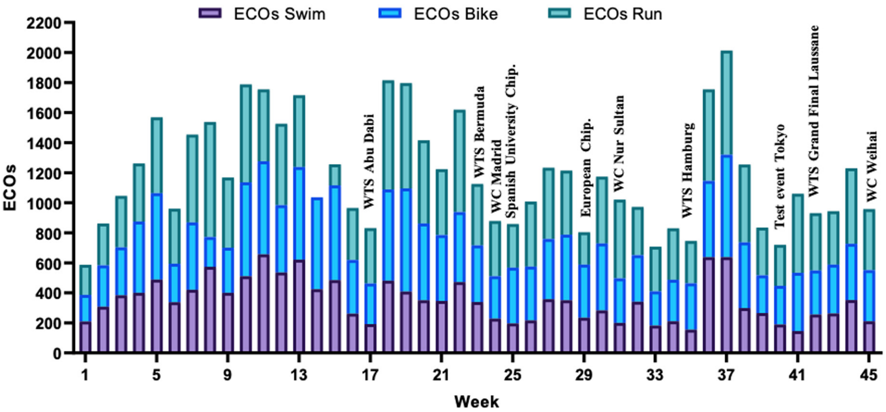

FIGURE 6 Training load (ECOs) by segment of triathlete B in 2019 season. Chip., Championship; ECOs, Equivalentes de Carga Objetivos (Spanish language); WC, World Cup; WTS, World triathlon series.

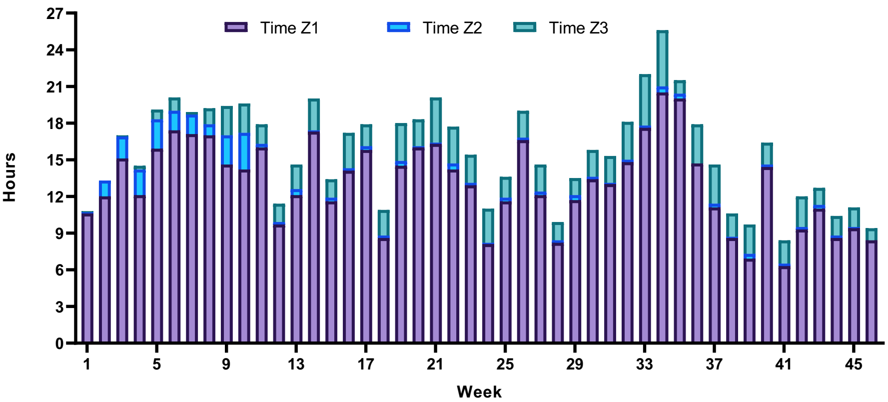

FIGURE 7 Weekly training volume and training intensity distribution of Triathlete A in 2019 season. Z, Zone.

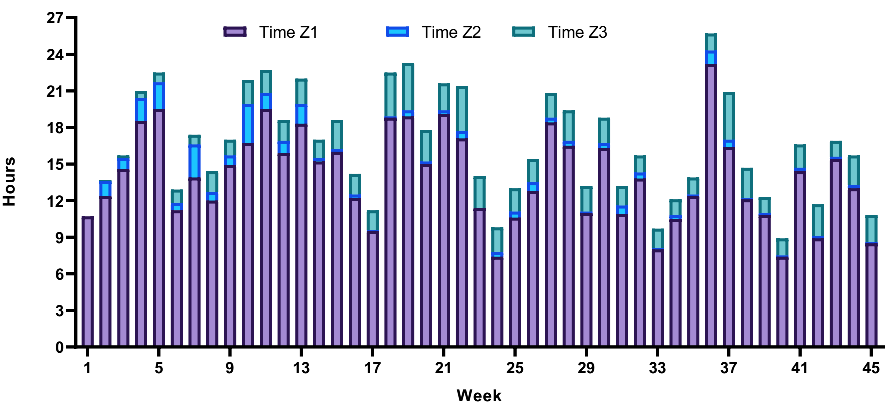

FIGURE 8 Weekly training volume and training intensity distribution of Triathlete B in 2019 season. Z, Zone.

athletes in other sport disciplines.[8,10] Rønnestad and Hansen[8] reported an average of 12 h of weekly training for an elite cyclist, while Keneally et al.[10] reported around 9 h (140 km weekly) in a case study on a world-class 5000-m track and field athlete. Triathletes must develop their performance in three sport modalities. Therefore, greater weekly training hours could be necessary. Recently, Gallo et al.[7] reported a higher training volume (≈17 h) for a three world-class cyclist who finished top-5 at Giro d'Italia. In this line, Casado et al.[45] increased the training volume to achieve high performance in long-distance runners. Specifically, it seems that it is necessary to run over 100 kms a week to compete with world-class athletes.[13,45] Training volume plays a crucial role in endurance sports because it allows improving the efficiency of key metabolic components that fuel energy.[46] Long-duration/low-intensity sessions lead to deep skeletal muscle adaptations, including increases in the mitochondrial content and respiratory capacity of muscle fibers.[47] This type of training also contributes to enhancing the ability to sustain high muscular power outputs for long durations and the ability to recover from high-intensity exercises.[48,49]

A polarized TID model (Polarization index >2.0) was elaborated for almost each season. This TID model has been commonly used for elite endurance athletes and it has been described as the "optimal" TID in several studies.[19,21] However, the TID reported in this case study represented the season's total TID average. In the 2019 season example, the TID changed from an HVT and a pyramidal distribution in the first weeks of the season to a polarized distribution, which was used as the main model from week 12 onwards. This evolution from a pyramidal distribution to a polarized one has been observed to be positive in other studies.[9,50] Filipas et al.[50] found that the evolution from pyramidal to polarized TID in a 16-week training block allowed to maximize performance improvements and some physiological variables such as $VO_{2peak,}$ and a velocity at 2 and 4 mmol/L of blood lactate concentration in a group of well-trained runners. Both the polarized and pyramidal models are characterized by a high amount of accumulated training volume (hours) at low intensity (≈80%). Long, easy training workouts are not only essential to accumulate high training volumes but also to favor the social aspects of training, facilitating enjoyment and camaraderie among teammates.[45] Despite the fact that a polarized TID model was mainly presented, the training load distribution followed the "50/50 rule" with around 50% of the ECOs in Zone 1 and the other 50% in Zones 2 and 3.

Several studies have described the evidence-based superiority of Block Periodization compared to traditional periodization in both elite and well-trained endurance athletes.[51–53]

García-Pallarés et al.[53] showed the significant superiority of Block Periodization in Kayak performance, earning an Olympic gold medal with this model of periodization. In this study, the same physiological adaptations (VO_{2peak} and VO_2 at VT2) were observed, together with greater adaptations at a paddling speed of VO_{2peak} and power output at VO_{2peak} in 12 weeks of Block Periodization than in 22 weeks of Traditional Periodization.[53] In this line, Rønnestad et al.[52] also found greater effects on VO_{2max} and a 40-min all-out trial in a well-trained cyclist after 12 weeks of Block Periodization compared to Traditional Periodization. Based on this evidence and considering that triathletes do not have many weeks before their first international competition, the three-block periodization (ATR) model could be appropriate at the beginning of the season to reach competitive performance levels faster than using a traditional model. Rønnestad et al.[16] also showed that a 5-week block periodization had a greater effect on aerobic power, VO_{2max}, and power output at 4 mmol/L of blood lactate concentration in elite cross-country skiers compared to a traditional periodization, which apparently had no effect on these performance variables. Triathletes in this case study had between 3 and 5 weeks to prepare between the first competition and their next competitive block. For this reason, the block periodization model seems to be appropriate to increase the performance of elite athletes within a short period of time, each training block focusing on developing one or two performance targets. Conversely, some studies have failed to find any differences between the use of a traditional or block periodization model.[17,54] Solli et al.,[54] however, found only one block of competitions at the end of the season and Almquist[17] found that the participants' performance was inferior (trained cyclists, $VO_{2max} = 58 \pm 8$ mL/kg/min).

Altitude training camps lasted three to 4 weeks at an altitude of ≈2300 m. This duration and altitude seem to be appropriate to optimize the adaptations and increase the performance of endurance athletes.[55] It is worth remembering that altitude training sessions, as well as those carried out in extreme heat conditions imply additional stress and a greater training load for triathletes.[56]

This study presented a number of limitations. The training process of two youth category triathletes was examined until maximum competitive performance was reached. Yet the data cannot be extrapolated to other populations such as non-elite athletes. In addition, the context in which athletes have developed their performance (training group, training place, coaches) makes the process unique and possibly unrepeatable for other elite athletes. Therefore, the data shown here can only serve as a general guide. Coaches can use them, but they must be adapted to their athletes' characteristics. In addition, a lack of studies on the detailed training characteristics of other high-performance male triathletes makes it difficult to compare our results. We only found the case study of a triathlete preparing for the Olympic Games.[9] This athlete, however, also belonged to the same training group, so the training methodology was similar. It would thus be interesting to compare our results with that of other international triathlon training groups. Finally, it is important to remember that there is no single path toward high performance, and it is impossible to know whether these triathletes would have achieved the same result or even better results following a different training program.

5 | PRACTICAL APPLICATIONS

This case report can be used for research purposes and by endurance sports coaches to understand the process of progression toward an international elite level of performance in triathlon. The training load and the physiological progress until reaching a top level were presented together with the competition dynamics and the obtained results.

6 | CONCLUSIONS

This case report showed that the following factors must be considered to achieve a top international level in short-distance triathlon: progression in training load; improvements in physiological variables; and participation in international events starting from youth categories. Reaching certain physiological values such as a high VO_{2max} (>80 mL/kg/min), as well as placing the VT2 close to 90% of the VO_{2max}, seems necessary to compete at the highest level in triathlon. In cycling, values close to 7 W/kg in power associated with VO_{2max} and greater than 5 W/kg in power associated with VT2 should be achieved. The speed associated with VO_{2max} should be greater than 21 km/h and the speed associated with VT2 close to 19 km/h in running. Lastly, regarding competitions, it seems relevant to have been successful both in Junior/U23 international categories and in the national elite category, before achieving good results at the highest international level.

7 | PERSPECTIVE

In recent years, several published case studies on elite athlete training has succeeded at unifying some of the sport sciences scientific evidence with the daily practice of international elite endurance athletes.[7–9,57,58] Due to the difficulties in obtaining elite athlete data, these publications should be considered as a major new line of research in sports science. Most of these works only show the athlete data for a season or a specific training block. The present study, however, described the long-term development of two elite endurance athletes. Therefore, it can serve as a guide for coaches who are currently working with talented young athletes.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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