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Research article

Power Profile during Cycling in World Triathlon Series and Olympic Games

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Abstract

This study aimed to analyze the power profile (PP) during the cycling segment of international-level triathletes in the World Triathlon Series (WTS) and Olympics and to evaluate the influence of circuit type, race distance (Sprint or Olympic distance) and race dynamics on the development of the cycling leg and the final race position. Four male triathletes participated in the study. Twenty races were analyzed using geolocation technology and power-meter data to analyze PP, race dynamics, and course characteristics. Before the races, incremental tests of volitional exhaustion with gas analysis were performed to determine power intensity zones. Nonparametric Mann-Whitney U tests and correlation analyses were conducted to identify differences and relationships between various variables. A correlation between the time spent above maximal aerobic power (MAP) and dangerous curves per kilometer ($r = 0.46$; $p < 0.05$) and bike split result (BSR) ($r = -0.50$; $p < 0.05$) was observed. Also, moderate correlation was found between BSR and the final race position ($r = 0.46$; $p < 0.01$). No differences were found between sprint and Olympic distance races in any variable. Power output variability, influenced by technical circuit segments, remains the main characteristic in international short-distance races. The results of the present study suggest that the triathletes who are better adapted to intermittent high intensity efforts perform better cycling legs at international high-level races.

Key words: Race dynamic, high performance, endurance, physiological variables, effort distribution, watts.

Introduction

The most significant events that a triathlete can participate in at the international level are the Olympics, where 55 participants (previously qualified through an Olympic ranking) compete (World triathlon, 2023) and the World Triathlon Series (WTS) (Cejuela et al., 2013). In WTS, a maximum of 55 triathletes can also participate (World Triathlon, 2023). To access the start list of a WTS event, a high position in the international ranking is required, which is achieved by obtaining good results in previous international competitions such as World Triathlon Cups and Continental Triathlon Cups (Piacentini et al., 2019). WTS events are primarily held over the Olympic distance (OD) (1.5 km swimming, 40 km cycling, and 10 km running) and Sprint distance (SD) (750m swimming, 20 km cycling, and 5 km running), with higher points awarded in the OD races. Short-distance triathlon races, which include OD and SD, allow drafting during the cycling segment (World Triathlon, 2023).

Conducting studies that analyze performance factors in competition is necessary for coaches to plan their training according to competitive demands. However, accessing data from high-level athletes can be challenging, making studies conducted with elite athletes of great value (Sandbakk et al., 2023). One of the variables that has been extensively analyzed in recent years, both in training and competition in cycling, is the power output. Power output can be used as an accurate monitoring tool to measure external load for coaches, athletes or sport scientists (Sanders and Heijboer, 2019). If these power outputs are studied and recorded in depth, we can define the athlete's power profile (PP) as a historical record of the athlete's capabilities to generate power in various circumstances (Allen, 2019). The study of the PP has gained popularity as a method of monitoring endurance cycling performance (Valenzuela et al., 2023). In road cycling, there are several studies analyzing the PP of professional cyclists in training and competition (Mateo-March et al., 2022b; 2022a; Muriel et al., 2021a; 2021b; Valenzuela et al., 2022). But few studies of this kind exist for international level triathlon. Some studies have described PP in World triathlon cups (Le Meur et al., 2009; Smith et al., 1999), in WTS (Etxebarria et al., 2014) or in long distance triathlon (Abbiss et al., 2006) but no data analysis has been conducted on summer Olympic triathlon events.

Analyzing how external factors can affect PP and race dynamics can be very useful when preparing for races at this level. Wu et al. (2014) described several external factors that can affect pacing in triathlon including topography, duration of the event, influence of other competitors and drafting. Factors such as topography (Le Meur et al., 2009) or the technical level of the circuit can affect the power developed in competition, as well as the number of accelerations (Etxebarria et al., 2014). On the other hand, the duration of the cycling segment also appears to affect the levels of fatigue that are experienced by the triathlete (Abbiss et al., 2006). During shorter duration triathlon events (i.e., SD), the reduction in pace may be associated with metabolite accumulation and neuromuscular fatigue. Conversely, in longer duration triathlons (i.e. Ironman) fatigue is associated with reductions in muscle glycogen content and neuromuscular activity (Wu et al., 2014). However, there are no studies that have examined the differences in PP or pacing between SD and OD races in high-level international competitions. Lastly, the race dynamics and benefit from drafting (Bentley et al., 2008) will also influence PP and the final competition results (Wu et al., 2014). It is suggested that not being in the first group at the start of the cycling segment and having to complete the cycling leg in the chasing group involves cycling at a higher speed during the initial part of the segment in an attempt to catch up with the leading group (Vleck et al., 2006). This extra effort in the cycling segment can negatively affect

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the performance in the running segment and subsequently the final competition result (Vleck et al., 2006; Walsh, 2019). Bernard et al. (2007) also demonstrated that variable intensity efforts during cycling affected running performance compared to more constant efforts. Along these lines, Piacentini et al. (2019) analyzed all the WTS between 2009 and 2016, concluding that it is of vital importance that the best runners start the running segment in the first group in order to have a good final result.

Although there are studies that have analyzed and described the development of various races and correlated this data with the final performance (Figueiredo et al., 2016; Landers et al., 2008; Le Meur et al., 2009; Piacentini et al., 2019; Smith et al., 1999), only Etxebarria (2014) published power data in WTS competitions. However, in Etxebarria's study (2014), laboratory evaluation data of the cycling performance is not provided, so we cannot observe the level of fatigue that was experienced by these triathletes while exerting the power in competition. Thus, the aim of this study was not only to analyze the PP of a representative number of WTS and the Olympic game race, but also to observe the degree of effort that exerting that power in competition may induce in triathletes. We intended to compare the effort made in SD and OD races. In so doing, we aim to build a better understanding of the actual demands of the cycling segment and their relationship with the type of circuit, distance and race dynamics, and how this can influence the final result of the race. The main hypotheses were: 1) The greater presence of technical sectors would increase the power records of the participants; 2) SD races would have higher power records and will be performed at a higher intensity than would OD races.

Methods

Study design

This study was executed in two distinct stages: laboratory testing and record and analysis of race data. The laboratory phase focused on conducting an incremental cycling test with gas analysis to calculate power intensity zones. The test was performed at the end of the specific training period (before the start of the competitive period).

Participants

A total of four male triathletes participated in the study, three of whom were world class and one of whom was of an elite-international level according to McKay's framework for research in sport science (McKay et al., 2022) . Their mean (±SD) age, height, and weight were 24.5 ± 2.89 years, 174.5 ± 6.9 cm, and 62.15 ± 3.5 kg, respectively. The participants were regular WTS competitors with a mean (±SD) number of years of experience of 4.5 ± 3.4 yr. Table 1 shows information related to physiological data, performance and competitive experience of the triathletes. All participants underwent a medical examination at the beginning of the season to verify that they were prepared for high-intensity exercise. All procedures used in this study were approved by the Alicante University Ethics Committee (UA-2023-10-27_2 expedient). The athletes gave their consent for their data to be published in this study. The whole data collection process followed the guidelines of the Declaration of Helsinki.

Laboratory Test

Incremental tests of volitional exhaustion were conducted to determine power intensity zones and analyze the performance in cycling. A ramp protocol was performed for cycling on a roller (Cycleops® The Hammer, United States) starting at 150 W and increasing 5 W each 12 s (Muñoz et al., 2014). The triathletes used his own bikes and the same power meter model attached to the bike (NG road, power2max®, Germany) to perform the test. The cycling tests were performed in the same room with the same temperature (21°C) and relative humidity (36.7%).

Table 1. Physiological, training zones, and race experience data over the seasons.

		SEASON 2021				SEASON 2022				SEASON 2023			
		A	B	C	D	A	B	C	D	A	B	C	D
PHYSIOLOGICAL DATA	VO_{2max} (ml/kg/min)	84.0	-	82.2	-	-	82.1	82.4	80.1	-	82.3	-	-
	% VT_2	89.8	-	90.1	-	-	90.3	90.3	89.3	-	90.2	-	-
	% VT_1	70.8	-	71.0	-	-	71.2	71.0	72.2	-	71.0	-	-
	MAP	495	-	465	-	-	428	467	415	-	430	-	-
	W at VT_2	405	-	365	-	-	346	367	335	-	347	-	-
	W at VT_1	285	-	280	-	-	265	280	255	-	265	-	-
	W/Kg at MAP	7.5	-	7.2	-	-	7.1	7.3	7.1	-	7.1	-	-
	W/kg at VT_2	6.1	-	5.6	-	-	5.7	5.7	5.8	-	5.7	-	-
	W/kg at VT_1	4.3	-	4.3	-	-	4.3	4.4	4.4	-	4.4	-	-
TRAINING ZONES	Phase 1 (W)	<280	-	<280	-	-	<265	<280	<255	-	<265	-	-
	Phase 2 start (W)	285	-	280	-	-	265	280	255	-	265	-	-
	Phase 2 end (W)	405	-	365	-	-	346	367	335	-	347	-	-
	Phase 3 start (W)	405	-	365	-	-	346	367	335	-	347	-	-
	Phase 3 end (W)	495	-	465	-	-	428	467	416	-	430	-	-
	Phase 4 (W)	>495	-	>465	-	-	>428	>467	>416	-	>430	-	-
RACE EXPERIENCE	Years of experience in international level races *(n)*	12	-	5	-	-	5	6	4	-	6	-	-
	Personal best WTS Ranking *(n)*	3	-	9	-	-	20	9	49	-	20	-	-

Abbreviation: A: triathlete A; B: triathlete B; C: triathlete C; D: triathlete D; VO_{2max}: maximum oxygen uptake; VT_2: second ventilatory threshold; VT_1: first ventilatory threshold; MAP: maximum aerobic power; W: watts; W/kg: watts relative to body weight; WTS: world triathlon series; n: number.

Gas analysis

The tests were performed using a portable gas-exchange analyzer (Cosmed® K5, Italy). During the test, the variables that were measured were: 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 ($P_{ET}CO_2$). Maximal oxygen uptake (VO_{2max}) was established as the average of the highest VO_2 value obtained for any continuous 1 min period. Maximal aerobic power (MAP) was defined as the average of the highest power output values recorded during a 1min period (Le Meur et al., 2009). To establish physiological markers, the Davis criteria were used (Davis, 1985). The first ventilatory threshold (VT_1) was determined using the criteria of an increase in both VE/VO_2 and $P_{ET}O_2$ with no increase in $V.E/V.CO_2$. The second ventilatory threshold (VT_2) was determined using the criteria of an increase in both VE/VO_2 and VE/VCO_2 and a decrease in $P_{ET}CO_2$. Two independent observers identified VT_1 and VT_2.

Determination of power intensity zones

To analyze the demands of the competitions, power intensity zones were determined. Four phases were defined and calculated as follows: below power at VT_1 (phase 1), between power at VT_1 and VT_2 (phase 2), between power at VT_2 and MAP (phase 3), and above MAP (phase 4) (Le Meur et al., 2009).

Race selection

To obtain a correlation coefficient of at least 0.600 with a significance level of 0.05 and a statistical power of 80%, a minimum of 19 races was needed. The statistical software Epidat 4.0 (Epidat, DXSP, Spain) was used to perform the sample size estimation. A total of 20 races were analyzed, among which 12 records were OD and 8 were SD. A total of 19 records were registered in WTS races and 1 record was registered during the Olympic triathlon event in Tokyo 2021. Four of them were registered in 2023,12 in 2022 and 4 in 2021. Competition data was recorded for at least one participant in 89% of the WTS that were run in either OD or SD between 2021 and July 2023. The races that were recorded depended on the season schedule of each athlete, being dependent on whether the participant was called to participate or if it coincided with their planning. Table 2 shows the stages of OD or SD WTS between 2021 and July 2023 and the number of athletes whose data were analyzed.

Description of circuits

A consensus was conducted among three expert triathlon coaches using the Delphi method (Velez-Pareja, 2005) to distinguish the types of sections in a course (Abbiss et al., 2013). The type of sections were as follows: a) Uphill sections; b) Downhill sections; c) Flat sections; d) Technical sections; e) Curve; f) Dangerous curve.

Competition measurement

Speed (SP), inclination, ascent and distance were recorded using GPS geolocation technology, with specific cycling sensors attached to the bicycle (Garmin EDGE 1030, Garmin International®, Olathe, KS, USA).

Table 2. Stages of the World Triathlon Series in Olympic and sprint distance format since 2021 and number of athletes analyzed.

Year	Race	Distance	Number of athletes
2023	WTS Montreal	SD	1
2023	WTS Cagliari	OD	1
2023	WTS Yokohama	OD	1
2023	WTS Abu Dhabi	SD	1
2022	WTS Final Abu Dhabi	OD	2
2022	WTS Bermuda	OD	3
2022	WTS Cagliari	OD	2
2022	WTS Hamburg	SD	2
2022	WTS Leeds	SD	2
2022	WTS Abu Dhabi	SD	1
2021	WTS Hamburg	SD	1
2021	Olympic Games	OD	1
2021	WTS Leeds	OD	1
2021	WTS Yokohama	OD	1

OD: olympic distance; SD: sprint distance; WTS: world triathlon series.

The variables relating to the power output were measured using the participants´ own power-meters (NG road, power2max®, Germany). These powermeters were located in the crank spindle of the bicycle. Power-meters were regularly used in training and calibrated before each use to avoid measurement errors. The variables related to power output that were measured included: Mean power (MP); normalized power (NP), known as an MP calculation discarding the 0 power values (Jobson et al., 2009); maximal mean power (MMP) of 5, 30 and 60 seconds; time spent in each power phase (TP); relative time spent in each power phase (RTP) as a percentage of the total time; number of peaks of power output over MAP per Kilometer (NPP/km); relative power of MP in relation to body weight (RMP); relative power of NP in relation to body weight (RNP); the work as an amount of mechanical energy spent in kJ; the Work in each phase in relation to the total work (RWP); and the variability index (VI), understood as MP divided by NP. The VI can be defined as a measure of stress variability; a high VI (above 1.1) shows intermittent efforts that are representative of criterium cycling races or very hilly circuits ("Variability Index (VI) – TrainingPeaks Help Center," n.d.).

To analyze race dynamics, data related to time, position, bike split result (BSR) and the peloton in which the participant was located at the exit of T1, on each cycling lap, and on arrival at T2 were collected. All the data are available on the official website of the international triathlon federation (World Triathlon, n.d.)

Statistical analysis

The results of the average data of all the races are shown as mean ± Standard Deviation. The MP, NP, S and MMP of 5, 30 and 60 seconds for all the races were calculated using COROS training hub software (COROS Wearables Inc., CA, USA).

The nonparametric test of the Mann-Whitney U test was performed to detect the statistical differences between the variables in the SD and OD races. Cohen's d was calculated to estimate effect sizes (ES) (Cohen, 1988) of SD and OD races. Cohen's d is defined as follows: trivial: 0 - |0.2|, small: |0.2| - |0.6|, moderate |0.6| - |1.2|, large: |1.2| - |2.0| and very large: |2.0| - |4.0| (Hopkins, 2009). Interval of confidence to 95% and Mean difference as % was also calculated. Spearmans' bivariate correlation coefficient was used to determine the inter-relationships between circuit characteristics, race dynamics, PP and final position. The statistical software Statistical Package for Social Sciences (SPSS) 22.0 (SPSS Inc., Chicago, IL, USA) was used to analyze the data. For all analyses, significance was accepted at $P < 0.05$.

Results

Laboratory test and determination of power intensity zones

The results of the laboratory tests, the calculation of power intensity zones, and the competitive experience of the participants can be seen in Table 2.

Circuit description

Table 3 shows the distance, number of laps, positive ascent, proportion of segments of each circuit, curves per kilometer, and dangerous curves per kilometer of each circuit.

No significant differences were found in positive ascent, proportion of segments of each circuit, curves per kilometer, and dangerous curves per kilometer between SD and OD circuits. Significant differences were found in the number of laps ($p < .001$), with the average number of laps for OD being 8.86 ± 0.69 and for SD 5.40 ± 0.55.

Figure 1 displays a description of one of the WTS circuits analyzed and the power output record of a participant during one lap.

Race data

The data of SP, RMP, RNP, RTP and NPP/km of each race and the mean and standard deviation values are shown in Table 4.

The MMP values found were an average of 795 ±102 W for 5 seconds, 499 ± 62 W for 30 seconds, and 411 ± 48 W for 60 seconds. The average MP of all the analyzed races corresponded to 58.3% of MAP, while NP corresponded to 65% of MAP.

The RWP was 22 ± 5.8% for phase 1, 20.4 ± 4% for phase 2, 20 ± 3.5 % for phase 3 and 37.5 ± 10% for phase 4.

Table 3. Description of the circuits.

Event (distance)	Distance (km)	Laps (n)	Ascent (m)	Uphill (%)	Downhill (%)	Flat (%)	Technical (%)	Curves/km (n)	Dangerous curves/km (n)
WTS Montreal (OD)	20.1	6	33	0	0	82.69	17.31	3.58	0.30
WTS Cagliari (OD)	37.63	10	41	0	0	73.08	26.31	3.19	0.27
WTS Yokohama 23 (OD)	39.78	9	52	0	0	67.19	32.81	2.94	0.23
WTS Abu Dhabi 23 (SD)	20	5	75	0	0	60.75	39.00	3.25	0.25
WTS Abu Dhabi 22 (OD)	40.32	9	119	0	0	54.69	45.31	2.23	0.22
WTS Bermuda (OD)	38.80	8	356	8.7	25.57	43.30	22.47	2.89	0.21
WTS Hamburg (SD)	21.06	6	47	0	0	80.91	19.09	2.56	0.28
WTS Leeds 22 (SD)	20.65	5	212	28.3	30.75	17.99	19.69	1.69	0.24
WTS Abu Dhabi 21 (SD)	18.27	5	81	0	0	66.06	33.94	3.28	0.27
Olympics Tokyo 21 (OD)	40.24	8	22	0	0	67.20	32.8	2.78	0.40
WTS Leeds 21 (OD)	37.71	9	433	18.9	34.8	22.29	23.99	1.67	0.24
WTS Yokohama 21 (OD)	39.24	9	53	0	0	50.69	49.31	3.44	0.46

WTS: World Triathlon Series; Km: Kilometer; n: number; m: Meters; %: Percentage; OD: Olympic distance; SD: Sprint Distance.

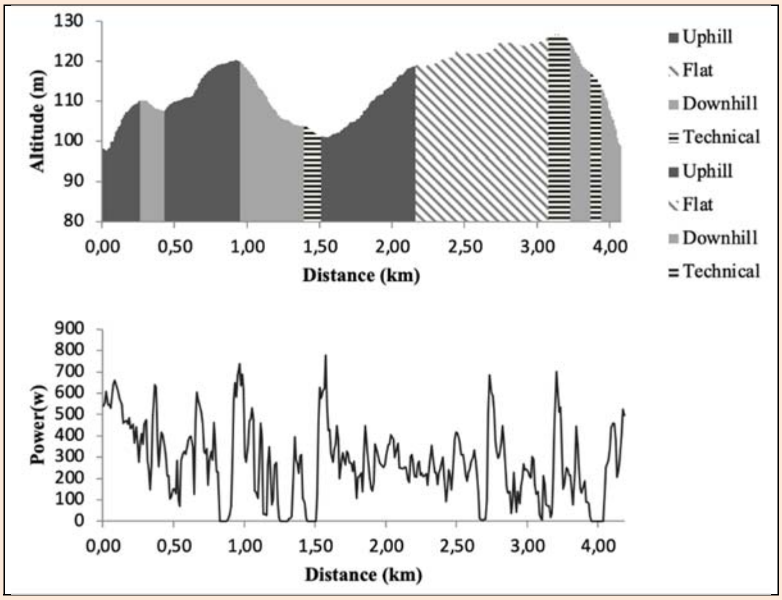

Figure 1. Example of course profile, location of splits and power output record for an individual lap of the WTS Leeds 22.

The most significant results that were found by the correlation analysis can be seen in Table 5.

When comparing race data between OD and SD, no significant statistical differences were found between RMP, RNP, SP, NPP/km, RTP1, RTP2, RTP3, RTP4 and RW phase 4. The differences found between SD and OD correspond to absolute values of time and watts spent in each power intensity zone and were: TP1, TP2, TP3, TP4 and WP4. Table 6 provides a detailed comparison between SD and OD races.

Table 4. Average speed, mean and normalized power relative to body weight, relative time spent in phase 1,2,3 and 4, number of peaks of power output over MAP per kilometer on 20 races.

ATHLETE - EVENT		SP (km/h)	RMP (W/kg)	RNP (W/kg)	RTP1 (%)	RTP2 (%)	RTP3 (%)	RTP4 (%)	NPP/km (n)
C	WTS Montreal 23	40.8	4.3	4.6	53.4	13.8	10.84	21.9	18.8
C	WTS Cagliari 23	44.2	4.0	4.4	60.2	15.3	10.0	14.5	11.6
C	WTS Yokohama 23	41.3	4.7	4.9	42.7	22.5	19.7	15.1	11.5
C	WTS Abu Dhabi 23	43.9	4.4	4.8	51.2	18.1	15.9	14.9	11.3
B	WTS Abu Dhabi 22	41.2	3.8	4.2	59.4	18.9	11.5	10.2	8.7
C	WTS Abu Dhabi 22	43.7	3.8	4.4	56.3	13.0	12.8	17.8	13.0
B	WTS Bermuda 22	39.1	4.1	4.8	52.6	17.3	12.4	17.7	15.9
C	WTS Bermuda 22	39.3	3.8	4.5	59.1	123.0	14.0	13.9	12.5
D	WTS Bermuda 22	39	4.1	4.9	55.0	14.1	12.8	18.1	15.7
C	WTS Cagliari 22	44	3.8	4.2	59.8	14.0	12.7	13.5	11.0
D	WTS Cagliari 22	43.2	4.1	4.5	59.5	14.1	11.3	15.0	12.2
B	WTS Hamburg 22	41.3	4.6	4.9	43.3	23.1	15.7	17.9	14.9
C	WTS Hamburg 22	43.1	4.1	4.4	51.8	19.2	14.3	14.7	12.0
B	WTS Leeds 22	38.5	4.5	5.0	42.7	27.5	18.7	11.2	9.6
C	WTS Leeds 22	40.8	3.9	4.5	57.3	17.1	13.9	11.7	9.8
B	WTS Abu Dhabi 21	39.4	4.1	4.7	52.8	14.8	12.6	19.8	16.9
C	WTS Hamburg 21	40.6	4.3	4.6	44.9	13.7	12.1	29.3	13.4
A	Olympics Tokyo 21	40.6	4.6	5.2	49.6	17.3	10.0	23.1	19.5
A	WTS Leeds 21	40.1	4.6	5.6	43.0	20.9	14.1	22.0	19.0
A	WTS Yokohama 21	43.1	4.8	5.3	44.0	18.0	11.7	26.3	20.6
Average ± sd		41.4 ± 1.9	4.2 ± 0.3	4.7 ± 0.4	51.9 ± 6.5	17.3 ± 3.9	13.3 ± 2.6	17.4 ± 5	13.9 ± 3.6

SP: average speed; VI: variability index; RMP: relative mean power; RNP: relative normalized power: RTP: relative time spent in phase; NPP/km: number of peaks of power output over maximal aerobic power per kilometer; WTS: world triathlon series; km/h: kilometer per hour; W: watts; W/kg: watts per kilogram; %: percentage; n: number.

Table 5. Correlation study.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1) Result	1.0																	
2) NPP/km	-.11	1.0																
3) Speed	.01	-.33	1.0															
4) RMP	.09	**.46***	-.22	1.0														
5) RNP	-.03	**.56***	**-.55***	**.83†**	1.0													
6) RTP1	-.11	-.27	.36	**-.84†**	**-.75†**	1.0												
7) RTP2	.19	-.17	-.06	**.52***	.41	**-.65†**	1.0											
8) RTP3	.04	-.39	-.13	.17	.24	**-.51***	**.48***	1.0										
9) RTP4	-.02	**.86†**	-.17	**.63†**	**.57†**	-.44	-.15	-.29	1.0									
10) RWP4	-.09	**.88†**	-.08	.39	.37	-.15	-.38	**-.51***	**.92†**	1.0								
11) Ascent	-.18	-.16	**-.52***	-.11	.24	-.10	.11	.42	-.29	-.34	1.0							
12) VI	-.28	.22	-.34	-.28	.17	.32	-.31	-.04	-.04	.10	**.54***	1.0						
13) D.curves/km	-.05	.35	.34	.54	.09	-.21	.08	-.37	**.46***	**.48***	**-.80†**	**-.52***	1.0					
14) DL.T1-DL.T2	-.24	**.55***	.12	.34	.17	-.21	-.20	-.28	**.64†**	**.49†**	-.29	-.06	**.48***	1.0				
15) Bike group	.72†	-.02	-.30	.06	.13	-.28	.28	.16	-.06	-.19	.13	-.11	-.35	-.37	1.0			
16) Dif. leader t1	**.41***	0.00	.02	-.21	-.13	.18	.01	-.13	-.15	-.18	.05	.01	-.40	-.14	**.77†**	1.0		
17) BSR	**.46†**	**-.56***	-.11	-.09	-.08	.07	.31	.21	**-.50***	**-.63†**	.21	-.19	-.36	**-.83†**	.43	.29	1.0	
18) MAP	-.37	.34	.04	.01	.14	-.13	-.14	-.07	.32	.43	.01	.22	.28	.39	-.39	-.38	**-.58†**	1.0

*: significative correlation ($p < .05$); †: significative correlation ($p < .01$); NPP/Km: number of repetition of power output over maximal aerobic capacity per kilometer; RMP: mean power relative to body weight; RNP: normalized power relative to body weight; RTP1: percentage of time in phase 1: RTP2: percentage of time in phase 2: RTP3: percentage of time in phase 3; RTP4: percentage of time in phase 4; RWP4: percentage of work in phase 4. VI: variability index; D.curves/km: dangerous curves per kilometer; DL.T1-DL.T2: difference of time with the leader in transition 2 minus difference of time with the leader in transition 1; Bike group: bike group where the athlete was located; Dif.leader t1; difference with the leader in transition 1; BSR: bike Split result; MAP: maximal aerobic capacity.

Discussion

The aim of this study was to analyze the PP in WTS and the Olympic race to assess the level of effort it represents for triathletes and how the latter can change depending on the type of circuit, distance and race dynamics, and, lastly, how this can influence the final result of the race.

Our main findings were that the number of dangerous curves can affect the intensity at which the triathlete competes, increasing the number of efforts over MAP. Correlations were also found between the triathlete's ability to sustain efforts above MAP and VT_2 and performance in the cycling segment. And finally, no differences were found between the PP or race dynamics between SD and OD triathlons.

Table 6. **Comparison between Olympic distance and Sprint distance values. Data are means (±SD).**

Variable	OD Average	SD Average	ES (dCohen)	p	IC 95%	MD (%)
RMP (w/kg)	4.2 ± 0.4	4.2 ± 0.2	-.25	.56	(-.41; .24)	-2.1
RNP (w/kg)	4.7 ± 0.4	4.7 ± 0.2	-.14	.77	(-.30; .40)	1
SP (km/h)	41.6 ± 2	41 ±1.8	.27	.56	(-1.31; 2.34)	1.24
NPP/km	14.3 ± 3.8	13.3 ± 3.3	.26	.57	(-2.53; 4.42)	6.63
RTP1 (%)	53.4 ± 6.9	49.67 ± 5.4	.59	.21	(-2.35; 9.88)	7.05
RTP2 (%)	16.5 ± 3.1	18.4 ± 4.8	-.48	.30	(-5.60; 1.85)	-11.34
RTP3(%)	12.7 ± 2.5	14.2 ± 2.5	-.59	.21	(-3.91; .93)	-11.68
RTP4 (%)	17.3 ± 4.6	17.7 ± 6	-.08	.87	(-5.35; 4.56)	2.29
RWP4 (%)	38.1 ± 1.1	36.6 ± 11.7	.14	.76	(-8.34; 11.28)	3.86
TP1 (seconds)	1690 ± 296	861 ± 86	4.17	<.001*	(600.87; 1056.93)	49.05
TP2 (seconds)	527 ± 126	320 ± 86	1.85	<.001*	(99.56; 314.77)	39.28
TP3 (seconds)	403 ± 90	247 ± 43	2.07	<.001*	(83.56; 228.36)	38.76
TP4 (seconds)	547 ± 165	312 ± 131	1.54	.003*	(83.56; 228.36)	42.96
WP4 (Kjs)	324 ± 128	179 ± 88	1.26	.01*	(34.67; 255.08)	44.75

*: Significative correlation ($p < .05$); ES: effect size; p: statistical significance; IC 95%: interval confidence 95%; MD: mean difference; %: percentage; OD: olympic distance; SD: sprint distance; RMP: relative mean power; RNP: relative normalized power; SP: speed; NPP/Km: number of repetition of power output over MAP per kilometer; RTP1: percentage of time in phase 1: RTP2: percentage of time in phase 2: RTP3: percentage of time in phase 3; RTP4: percentage of time in phase 4; RWP4: percentage of work in phase 4; TP1: time in phase 1; TP2: time in phase 2; TP3: time in phase 3; TP4: time in phase 4; WP4: work in phase 4; W/kg: watts per kilogram; km/h: kilometer per hour; Kjs: kilojoules.

In the present study, triathletes showed a high VO_{2max} (>80 mL/kg/min), similar values as reported for other top endurance athletes such as a professional cyclist (87 mL/kg/min) (Rønnestad and Hansen, 2018) or top international marathon runners (81.0 ± 4.0) (Legaz-Arrese et al., 2011). Triathletes also achieved a relative power value at VO_{2max} and at VT_1 and VT_2 slightly higher that U23 cyclists but below professional cyclists (Alejo et al., 2022). Comparing these results with samples of amateur triathletes, considerable differences can be observed in the values of VO_{2max}, power at VT_1 and power at VT_2 (Aoyagi et al., 2021; Barbosa et al., 2023). Nevertheless, the results of these variables in the present study are also slightly higher than those published by Le Meur (2009) in triathletes who competed in world triathlon cups in 2007 (the highest level of competition at that time, excluding Olympic games) or by Díaz et al. (2009) in elite triathletes belonging to the Spanish national triathlon team. Regarding the data that have been collected within competition, as compared to those of Le Meur (2009), in this study the values of MP (263 W), RMP (4.2 W/kg) and SP (41.4 km/h) were similar at MP (265 W), but the RMP (3.96 W/kg) and SP (40.7 km/h) were slightly lower. Greater differences can be found when the data from this study are compared with those of Smith (1999) in terms of MP (238 W), RMP (3.9 W/kg) and SP (39.8 km/h). Similarly, the SP at which the cycling segment was performed in OD races was higher than the average of all WTS races recorded between 1989 and 2019 (39,02 km/h) (Gadelha et al., 2020). Regarding Etxebarria et al. (2014) (which includes 3 WTS races), we find that the values of RMP (3.9 W/kg) were also slightly lower. Regarding the values of MMP, both studies had similar results. The values of VI were also similar and correspond to a typical flat criterium or hilly criterium cycling races ("Variability Index (VI) – TrainingPeaks Help Center," n.d.). The differences found in the variables mentioned above may be due to the fact that the sample of the present study may have better performance, suggesting that the current level in the cycling segment has increased. But it could also be due to differences in data collection methods, such as using different gas analysis equipment, measurement protocols, or power meters (Sitko et al., 2020). Another difference with previous researches can be observed if we analyze the percentage of MAP at which the cycling segment is performed. In the study of Le Meur et al. (2009) the percentage of MAP that was attained was 61.4%, a slightly higher result than that which was recorded within the present study (58.3%) and a similar result to those recorded by amateur triathletes in OD triathlons (61.3%) (Aoyagi et al., 2021). Nevertheless, amateur triathletes spent more time in phase 2 and 3, but much less in phase 4 in compare with elite triathletes. Therefore, it is possible that one of the characteristics that differentiates international races from other lower level races would be spending more time at intensities above MAP. Hence, in line with Bentley et al. (2002), triathletes with better abilities to perform high-intensity efforts might have better performance in the cycling leg and, additionally, might be less affected by demanding cycling segments, which could make them achieve better running splits (Bentley et al., 2008).

Triathlon's cycling segments are thus characterized by continuous fluctuations in power output values due to, among others, the technical characteristics of the circuit (Etxebarria et al., 2014). Despite this general consensus, there is not much scientific literature that have directly correlated the circuit's characteristics such as the number of curves or the presence of hills with the power output values or racing dynamics. In the present study, the positive correlation between the number of dangerous curves per kilometer and RTP4 and RWP4 shows that technical circuits cause athletes to have to make more efforts above MAP. Skilled triathletes could have greater energy savings that can translate into better performances in the running segment, where the greatest performance differences are found (Piacentini et al., 2019). Having good technical skills on the bike is therefore an essential characteristic that international level triathletes must have. A moderate correlation was also found between the seconds gained on the leader during the cycling segment and dangerous curves per kilometer, which could mean that technical circuits might be more conducive for chase groups to reduce the gap with the leading group. This could be because chase groups might take more risks when cornering in order to catch up to the lead group, which could lead to reduced gaps. Analyzing the relationships between race dynamics and PP, a high correlation between the seconds gained on the leader during the cycling segment and RTP4 and a moderate correlation with RWP4 was found. However, in line with Piacentini (2019), no further differences in the PP between chasing and leading groups were found. A high correlation between the BSR and NPP/km, RTP3, RTP4 and MAP was also found. This could be due to the characteristics of the WTS circuits, where curves require abrupt reductions and increases in speed and it is not possible to maintain constant efforts for a long time. Therefore, making high intensity efforts on the sectors where higher power output values can be exerted could be more effective than trying to maintain a constant effort throughout the race. With these results, we can conclude again that the ability to exert efforts above $V.T_2$ and MAP is a key factor in competitive performance. It may also have implications for training design, emphasizing the need to develop specific adaptations that allow triathletes to sustain and recover from efforts above this intensity zones.

The variables that correlate with the final result were the time differences with the leader at transition 1, the cycling group where the participant was located during the race and BSP. Therefore, the final result of the race will be greatly influenced by the development of the cycling segment, being crucial to remain in leading groups to start the running segment with the rest of the competitors.

Correlations were found between the total ascent and VI. This correlation may be due to the fact that a greater number of downhill sections result in longer periods where the generated power is equal to 0. When normalizing the power values, this would lead to an NP increase, which, when calculating the VI values, would entail higher values compared to flat circuits, where non-pedaling episodes are much shorter due to the circuit characteristics ("Variability Index (VI) – TrainingPeaks Help Center," n.d.). However, analyzing the correlations between the presence of uphill sections and PP, no significant correlation was found. This result contradicts the findings of previous studies on road cycling, in which power output differences were found based on topography. In those studies, hilly races presented higher power values than flat races (Sanders and Heijboer, 2019), a result we expected to happen in the present study. This difference from that of cyclists could be due to the lower anaerobic capacity of triathletes compared to cyclists (Arslan and Aras, 2016). Nevertheless, Le Meur et al. (2009) did not found increases in power during the uphill segment in a world triathlon cup men's race. The latter could indicate that the circuit elevation profile does not imply changes in triathlete demands in the cycling segment of international level triathlon races.

If the influence of the duration of the segment on the PP is analyzed, expected differences were found in the time and work performed in each power intensity zone. These differences are due to the longer total time of the race, as no statistically significant difference was found in relative time and work spent in each power intensity zone. No significant differences were found in power output values between OD and SD, which is noteworthy because, from the perspective of the power-duration relationship, longer durations of this segment in OD races should result in lower average power output. (Burnley and Jones, 2018). However, the cycling segment in short-distance triathlons can be defined as high-intensity activities characterized by intermittent bouts of effort. Therefore, in these types of races, where power is not applied regularly until task failure occurs, we cannot assume any direct relationship between power and duration (Burnley and Jones, 2018). No significant differences were found in MMP and SP values between OD and SD races, results that equally demonstrate the similarities between both distances. Due to this similarity it could be concluded that in OD races, cycling becomes more important as its longer duration will make it much more demanding. This information is very important for coaches since in the preparation for an OD triathlon, greater relevance must be given to cycling training than in SD, as the development of the cycling segment will be very similar in both distances but for twice the time in OD. Therefore, the running segment can be severely affected, as well as the final result, if the athlete does not arrive to the race with an appropriate level of preparation to OD races. However, future studies are needed to corroborate this hypothesis.

Nevertheless, this observational work presents a number of limitations. The findings should not be generalized to all participants in WTS and Olympic events since the sample size is not large. Another limitation to consider is that the laboratory test (and, therefore, the calculation of power zones) was conducted at the beginning of the competitive period. In a WTS season, there can be a significant time difference between the first and last competitions, which could lead to minor changes in the triathlete's performance throughout the competitive period.

Conclusion

In this study, results suggest that PP and race dynamics is influenced by the presence of technical segments in the circuit. Relationships were found between the number of dangerous curves and the time spent in intensity zones above MAP. The MAP and the time that the triathlete spent above MAP and VT_2 also coincided with better BSP. With this data, it is possible to confirm that the final result of the race will depend largely on performance in the cycling segment, being essential to be able to maintain intermittent high intensity efforts for long periods of time and have technical skills on the bike. Therefore, high-intensity interval training combined with technical skills is essential for triathletes who want to compete in this level of races. As no differences were found in PP or race dynamics between OD and SD triathlons, the development of these skills will be more important in OD races, where the longer duration makes this segment more demanding.

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Key points

- The power profile in the cycling segment of the major triathlon events is characterized as non-linear, with power peaks being observed throughout the segment.
- No further differences between Olympic Distance and Sprint Distance were found for any relative variable.
- The presence of dangerous curves should be considered because it affects the PP and race dynamics.

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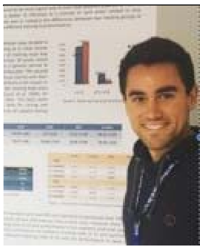

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