Distribution of Power Output during the Cycling Stage of a Triathlon World Cup

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ABSTRACT

BERNARD, T., C. HAUSSWIRTH, Y. LE MEUR, F. BIGNET. S. DOREL and J. BRISSWALTER. Distribution of Power Output during the Cycling Stage of a Triathlon World Cup. *Med. Sci. Sports Exerc.*, Vol. 41, No. 6, pp. 1296–1302, 2009. **Purpose**: The aim of this study was to evaluate the power output (PO) during the cycle phase of the Beijing World Cup test event of the Olympic triathlon in China 2008. **Methods**: Ten elite triathletes (5 females, 5 males) performed two laboratory tests: an incremental cycling test during which PO, HR at ventilatory thresholds (V_{T1} and V_{T2}), and maximal aerobic power (MAP) were assessed, and a brief all-out test to determine maximal anaerobic power output (MAnP). During the cycle part of competition, PO and HR were measured directly with portable device. The amount of time spent below PO at V_{T1} (zone 1), between PO at V_{T1} and V_{T2} (zone 2), between PO at V_{T2} and MAP (zone 3) and above MAP (zone 4) was analyzed. **Results**: A significant decrease in PO, speed, and HR values was observed during the race. The distribution of time was 51 ± 9% for zone 1, 17 ± 6% for zone 2, 15 ± 3% for zone 3, and 17 ± 6% was performed at workloads higher than MAP (zone 4). From HR values, the triathletes spent 27 ± 12% in zone 1, 26 ± 8% in zone 2, and 48 ± 14% above V_{T2}. **Conclusions**: This study indicates a progressive reduction in speed, PO, and HR, coupled with an increase in variability during the event. The Olympic distance triathlon requires a higher aerobic and anaerobic involvement than constant-workload cycling exercises classically analyzed in laboratory settings (i.e., time trial) or Ironman triathlons. Furthermore, monitoring direct PO could be more suitable to quantify the intensity of a race with pacing strategies than classic HR measurements. **Key Words:** SRM POWER METER, PACING STRATEGIES, MAXIMAL MEAN POWER, COMPETITION ANALYZIS, ELITE TRIATHLETES

During the last decade, studies focusing on factors affecting performance during an Olympic distance triathlon have identified the role of drafting position, power output (PO) production, cycling cadence selection, or previous locomotion mode on subsequent exercise as the main factors explaining changes in performance (8,14,15,22–25). However, these studies have been mainly conducted using an experimental design and recent studies analyzing cycling performance have highlighted a possible discrepancy between factors affecting performance during competition and those classically identified in experimental settings (e.g., (20,26–28)). One of the main differences is related to the constant PO used in experimental studies when compared with variable intensity observed in competition events where pacing strategies generate specific physiological or biomechanical constraints. Within this framework, pacing strategy has been defined as the within-race distribution of PO, speed, and cadence induced by voluntary adjustments to cope with the course of the competition (2,4,5,9). Thus, pacing strategy is described as a nonlinear dynamic system leading to particular metabolic and/or neuromuscular fatigue when compared with constant intensity exercise (for review, [1]). In elite Olympic distance triathlon, the athletes are allowed to draft during the cycle stage. This tactic probably affects pacing strategy. With the exception of a case report documenting PO during an Ironman triathlon (2), the only competition data available in Olympic distance triathlon are from the 1997 World Cup race of Sydney (Australia) in three triathletes (19). From a performance-optimization standing point, providing a comprehensive description of the physiological profile for this specific event could improve the knowledge of the Olympic distance triathlon and thus training strategies in elite athletes.

Recently, numerous studies have described the PO profile during professional cycling events (12,26–28) or mountain bike races (20) using lightweight portable power meters. In addition to PO and cadence, power meters also record speed and HR, providing important competition data for identifying the demands associated with successful performances. Results indicate that competition could be characterized by

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a specific power output profile corresponding to different physiological intensities expressed relative to the laboratory testing results. Furthermore, these authors indicate a difference between PO and HR measurement to determine competition intensity. Thus, using direct power output could be useful to determine training programs corresponding to the demands of international competitions.

During the 2 yr preceding the Olympic Games, an attractive competition, so-called “test event,” is organized by the International Triathlon Union (ITU) on the same circuit as the future race, allowing athletes and coaches to collect relevant information related to topographic and environmental conditions on technical bike courses. The Beijing ITU World Cup test event of the Olympic triathlon in China 2008 constituted an opportunity to characterize the cycling workload of world ranked elite triathletes. Therefore, the main aim of this study was to determine the variation of PO, cadence, and HR during the cycle phase of this specific World Cup triathlon. To our knowledge, this study is the first to quantify the distribution in power delivered in cycling within the individual discipline of elite, ITU World Cup, triathlon.

METHODS

Subjects. Ten elite triathletes (5 females, 5 males) of the French National Triathlon team were studied. All were competing on the ITU circuit and had an average World ranking of 30 (range, 7–52). They gave their informed written consent to participate in the study, which was conducted according to the Declaration of Helsinki. A local ethics committee for the protection of individuals gave approval concerning the project before its initiation. Their mean (±SD) age, height, and body mass were 26.9 ± 4.7 yr, 173.7 ± 6.9 cm, and 61.5 ± 6.0 kg, respectively.

Laboratory testing. Each subject performed two laboratory sessions. Three weeks before the competition, subjects undertook an incremental cycle test to exhaustion, to determine maximal oxygen uptake ($\dot{V}O_{2max}$), maximal aerobic power (MAP), and ventilatory thresholds (V_T). This laboratory session was conducted on a stationary electromagnetically braked cycle ergometer (SRM ergometer; Schoberer Rad Messtechnik, Jülich, Germany). The system is a crank-based device that measures the mechanical PO using strain gauges attached to components inside the crank. The measured torque and cadence values were digitalized inside the crank and converted to a high-frequency, pulse-width–modulated electrical signal. The data were transmitted to a microcomputer on the handlebar, where the torque was averaged over each complete pedal revolution and multiplied by the cadence to calculate the PO reading using the following equation

$$\text{power output} = ([\text{measured frequency} - \text{zero offset frequency}] \times \text{cadence} \times 2\pi)/(\text{slope} \times 60) \qquad [1]$$

The slope for each SRM crank dynamometer is calculated dynamically at the SRM factory. Positions of the handlebars, seat height, and crank length were adjusted to the measures used by the athletes on their own racing bike. After a 6-min warm-up at 100 W, further increments of 25 and 30 W were added every 2 min until exhaustion for women and men, respectively. During this test, oxygen uptake ($\dot{V}O_2$) and expiratory flow ($\dot{V}_E$) were collected, and RER was calculated from the ratio between oxygen uptake and carbon dioxide output ($\dot{V}CO_2/\dot{V}O_2$), using a telemetric system (Cosmed K4b^2, Rome, Italy). HR values were monitored using a Polar unit (S710i; Polar Electro, Kempele, Finland). Expired gases and HR values were averaged every 10 s. $\dot{V}O_{2max}$ and MAP were defined as the average of the highest consecutive $\dot{V}O_2$ and PO values recorded during a 1-min period. Moreover, the first and the second ventilatory thresholds (V_{T1} and V_{T2}, respectively) were determined according to the criteria previously described (6). V_{T1} was determined using the criteria of an increase in the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) with no concomitant increase in the ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$) and the departure from linearity of E. V_{T2} was established using the criteria of an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$. V_{T1} and V_{T2} were recorded by two independent observers. If there was disagreement, the opinion of a third investigator was sought. The physiological characteristics of our subjects are presented in Table 1.

The second laboratory session was a short and maximal all-out cycling test performed on the same ergometer to determine the maximal anaerobic power output (MAnP) for each subject. After a 15-min warm-up, subjects were asked to perform two maximal cycling sprints of 6 s in duration,

TABLE 1. Physiological characteristics of the subjects (females, n = 3; males, n = 5) recorded during laboratory testing.

Parameters	Females (mean ± SD)	Min Females	Max Females	Males (mean ± SD)	Min Males	Max Males
PV_{T1} (W)	186.7 ± 12.6	175	200	266.0 ± 18.5	235	280
PV_{T2} (W)	241.7 ± 14.4	225	250	336.0 ± 23.0	310	370
MAP (W)	296.3 ± 29.7	265	324	418.0 ± 26.8	400	460
Rel. MAP (W·kg^{-1})	5.4 ± 0.3	5.0	5.6	6.3 ± 0.6	5.8	7.4
MAnP (W)	676.7 ± 124.6	542	788	942.8 ± 119.2	830	1120
Rel. MAnP (W·kg^{-1})	12.3 ± 1.8	10.2	13.6	14.2 ± 2.0	12.0	16.5
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	67.3 ± 0.7	66.9	68.1	69.8 ± 5.3	65.9	78.9
HR_{max} (bpm)	185.7 ± 13.1	172	198	180.8 ± 5.4	175	187
Body mass (kg)	55.0 ± 2.6	53	58	66.4 ± 3.2	62	69

HR_{max}, maximal HR; MAnP, maximal anaerobic power; MAP, maximal aerobic power; PV_{T1}, power at first ventilatory threshold; PV_{T2}, power at second ventilatory threshold; Rel. MAnP, maximal anaerobic power relative to body weight; Rel. MAP, maximal aerobic power relative to body weight; $\dot{V}O_{2max}$, maximal oxygen uptake.

each one separated by at least a 4-min rest. Subjects were told to remain in the seated position and were vigorously encouraged to produce the highest acceleration possible. Total effective force (i.e., the propulsive force applied perpendicularly to the crank arm) was determined by the ratio between torque and the constant length of the crank arm. Effective force, crank angular velocity recalculated as pedaling rate, and power were averaged for the period of each pedal downstroke. After computation, the data from both sprints were used to draw the power–velocity relationship, respectively, using a second-order polynomial regression. MAnP was identified as the apex of the power–velocity relationship.

Test event. Race data were collected during the Beijing ITU World Cup (China, September 24, 2006) organized 3 wk after the World Triathlon Championship. The course of the competition was exactly the same as that of the Olympic event scheduled in 2008 in Beijing. The cycle phase of the test event consisted of six partly hilly (elevation change of 100 m per lap) 6.9-km laps, allowing comparisons of data observed among the different consecutive laps (Fig. 1).

Before the event, each subject's own bicycle was equipped with a mobile power measurement device (Professional SRM road version; SRM Training System, Schoberer Rad Messtechnik, Jülich, Germany). The SRM system records continuously and reliably power output (PO), cadence, HR, speed, and distance (13,17). The system weight of 300 g is comparable to a conventional bicycle crank and, therefore, does not influence performance. Because of a possible drift of the zero offset frequency, the device was calibrated systematically before the race. Data were collected at 1 Hz, and a compatible Polar unit (Team System, Kempele, Finland) allowed the recording of HR throughout the swim, cycle, and run phases of the triathlon. After the race, the data were transmitted from the registration unit to a personal computer for further processing.

Race data analysis. Similarly to previous studies on competitive cycling events (12,20,26), the total cycling phase time was divided into four zones of intensity on the basis of results from the graded exercise test in the laboratory, and the percentage of time spent in each zone was calculated as follows: below PO at V_{T1} (zone 1), between PO at V_{T1} and V_{T2} (zone 2), between PO at V_{T2} and MAP (zone 3), and above MAP (zone 4). In addition, zone 4 was divided in two parts (part 1, between MAP and 60% MAnP; part 2, above 60% MAnP). A similar analysis using HR values was also conducted: below HR at V_{T1}, between HR at V_{T1} and V_{T2}, and above HR at V_{T2}. The six laps (L1, L2, L3, L4, L5, ad L6) were combined in three sections (L1–L2, the initial phase; L3–L4, the middle phase; and L5–L6, the late phase). To reflect the freely chosen cadence of athletes, the nonpedaling time was excluded when calculating the mean cadence during each lap. In addition, the gear (meters per crank revolution) was calculated from speed and cadence values using the following equation:

$$\text{gear} = \text{speed} \times \text{time}^{-1} \times (\text{cadence} \times 60)^{-1} \qquad [2]$$

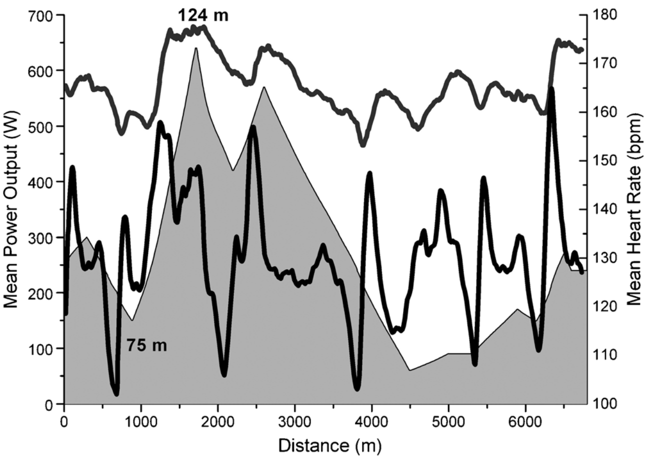

FIGURE 1—Example of the race profile (*filled area*) and smoothed plot of power output (*bold lower line*) and HR (*upper line*) of one male triathlete during a single lap (length, 6900 m; max difference in elevation, 100 m).

Statistical analysis. Descriptive statistics [mean, SD, coefficient of variation (CV), and range (min–max)] for PO, speed, cadence, HR, and gear were calculated for the six laps of the cycle phase. The effect of period (L1–L2, L3–L4, and L5–L6) were analyzed using a one-way repeated-measures ANOVA using PO, speed, cadence, and HR as dependent variables. A Newman–Keuls *post hoc* test was used to determine any differences between the sections. For all analyses, significance was accepted at $P < 0.05$.

RESULTS

Power output, speed, cadence, and HR during competition. Only eight athletes finished the race (Table 1). The triathletes completed the cycle phase of the triathlon in 66 ± 4 min at a mean PO of 230 ± 53 W (3.6 ± 0.5 $W \cdot kg^{-1}$, 60 ± 8% MAP), a speed of 38 ± 3 $km \cdot h^{-1}$, a cadence of 91 ± 5 rpm, an HR of 165 ± 5 bpm (91 ± 4% HR_{max}), and a gear of 6.4 ± 0.4 m per crank revolution. A significant decrease in PO, speed, gear, and HR values was observed during the race ($P < 0.05$; Table 2). Between the first (L1–L2) and last sections (L5–L6), PO, speed, HR, and gear decreased by 20.0%, 3.6%, 7.3%, and 6.5%, respectively. Conversely, the variability in PO and HR significantly increased across periods. No significant variation of cadence or changes in variability of speed, cadence, and gear was observed (NS).

Power output and HR demands during competition referring to the maximal tests performed in laboratory. The average distribution of time spent at different intensities (in % of MAP zones 1–4) was 51 ± 9% for zone 1, 17 ± 6% for zone 2, 15 ± 3% for zone 3, and 17 ± 6% for zone 4. In zone 1, a portion of the time spent was below 10%MAP and, therefore, represented times when the athletes were coasting downhill or freewheeling within the peloton. From HR values, the triathletes spent

TABLE 2. Percentage of maximal aerobic power (%MAP) and maximal HR (%HR_{max}), speed (S), cadence (Cad), gear (m per crank revolution), and the respective coefficients of variation (CV) during each section (L1–L2, L3–L4, L5–L6).

Sections	%MAP (%)	CV %MAP (%)	S ($km \cdot h^{-1}$)	CV S (%)	Cad (rpm)	CV Cad (%)	Gear (m per crank revolution)	CV Gear (%)	%HR_{max} (%)	CV HR (%)
L1–L2	66.0 ± 7.1	59 ± 7	38.2 ± 2.6	28 ± 2	91.1 ± 5.0	17 ± 7	6.6 ± 0.4	19 ± 2	94.0 ± 2.6	4 ± 1
L3–L4	60.7 ± 9.1*	66 ± 10*	38.0 ± 2.6	27 ± 1	91.3 ± 4.6	16 ± 5	6.4 ± 0.4*	19 ± 2	90.6 ± 4.1*	7 ± 2*
L5–L6	52.7 ± 7.5*†	77 ± 15*†	36.9 ± 2.5*	28 ± 2	90.9 ± 4.8	15 ± 3	6.2 ± 0.5*†	20 ± 1	87.2 ± 5.7*†	9 ± 2*†

Mean ± SD. $N = 8$.
* Significantly different from L1–L2.
† Significantly different from L3–L4.

27 ± 12% in zone 1, 26 ± 8% in zone 2, and 48 ± 14% above V_{T2} (zones 3–4). The main differences between periods were as follows (Fig. 2): 1) during L5–L6, an increase of time spent at low intensities ($P < 0.05$; below power at V_{T1}) and a decrease of time spent ($P < 0.05$) at moderate (below power at V_{T2}), high (below MAP), and very high intensities (above MAP); 2) when expressed as percent of maximal anaerobic power (MAnP), the time between 100% MAP and 60% of MAnP declined from 14.1 ± 5.9% (L1–L2) to 9.4 ± 2.8% (L5–L6) and the percentage of time spent above 60% of MAnP decreased from 5.5 ± 4.3% (L1–L2) to 3.8 ± 2.5% (L5–L6; $P < 0.05$).

DISCUSSION

This investigation is the first to analyze pacing strategies used by elite triathletes during the attractive test event of Beijing ITU World Cup preceding the Olympic triathlon in China 2008. Olympic events particularly increase the role of the cycle portion of a triathlon when compared with the swimming or the running part. Therefore, the present data should be considered as descriptive indicators for the workload sustained during Olympic events with this specific course design. Similarly to the Athens Olympic triathlon (2004), the Beijing Olympic triathlon (2008) will involve a predominantly hilly cycle section to better accommodate the needs of the viewing public. The main results observed were as follows: (a) a great variability in power output during and among the different laps of the cycle phase, (b) an increase in the variability of power output and HR values as the number of laps progressed, and (c) a decrease in power concomitant with HR, speed, and gear during the race without any cadence alteration.

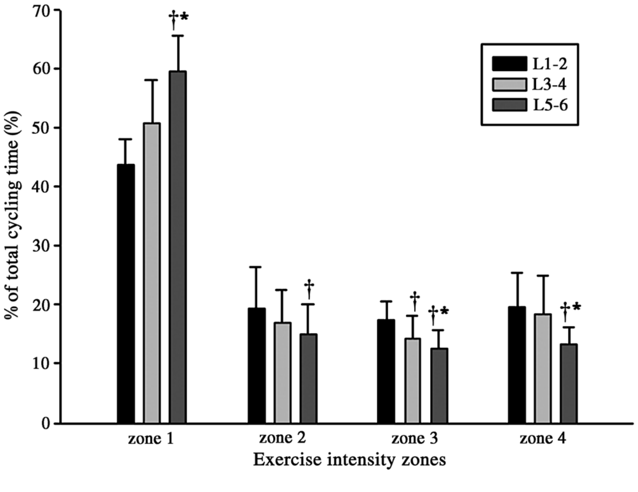

FIGURE 2—Percentage of total cycling time during each section (L1–L2, L3–L4, L5–L6) in exercise intensity zones: 1) below power output at first ventilatory threshold (zone 1; power output <64% MAP), 2) power output at second ventilatory threshold (zone 2; power output = 64%–81% MAP), 3) 100% of maximal aerobic power (zone 3; power output = 82%–100% MAP), and (4) above 100% of maximal aerobic power (zone 4). Mean ± SD. †Significantly different from L1–L2. *Significantly different from L3–L4. $P < 0.05$.

It has been well documented that the direct measurement of power output describes precisely performance in cycling (11,20,26,27). To date, only one study has analyzed the power output in cycling during the 180-km time trial of an Ironman triathlon (2). This previous study was the first to show the oscillatory patterns of power output that occur during a prolonged cycling part of a triathlon and their relationship with pacing strategy. However, contrarily to an Ironman, pacing strategies used in contemporary elite Olympic distance triathlon are influenced by several factors, especially the use of drafting (7). Furthermore, the profile of the race with many hilly sections or more technical bike courses may change the physiological demands during draft–legal competitions and induce tactical strategies that could increase variability in power output. The mean power output measured during the race was 173 ± 14 W (3.1 ± 0.1 $W \cdot kg^{-1}$) for the female triathletes and 265 ± 19 W (3.9 ± 0.4 $W \cdot kg^{-1}$) for the male athletes, for respective mean race durations of 72 and 63 min. These results could be compared with previous results recorded during cycle competition. The mean power output of women's World Cup cycle racing over flat and hilly profiles were 192 ± 21 W (3.3 ± 0.3 $W \cdot kg^{-1}$) and 169 ± 17 W (3.0 ± 0.4 $W \cdot kg^{-1}$), respectively (12). In men's professional road cycling (26), during multistages including an uphill time trial, the average power output measured was 245 ± 33 W (3.4 ± 0.3 $W \cdot kg^{-1}$), and during the Tour de France, the average power outputs during flat, semimountainous, and mountainous stages were 218 ± 21 W (3.1 ± 0.3 $W \cdot kg^{-1}$), 228 ± 22 W (3.3 ± 0.3 $W \cdot kg^{-1}$), and 234 ± 13 W (3.3 ± 0.2 $W \cdot kg^{-1}$), respectively (27). The slight differences with our data could be mainly explained by the fact that the cycling phase during an Olympic distance triathlon is shorter than the other mentioned races, approximately 1 h versus more than 3 h, respectively. Furthermore, the Olympic distance triathlon race is composed of several identical laps, thus repeated climbs, descents, and turns lead to a particular profile more similar to cycle criterion races with rapid accelerations at supramaximal power outputs and periods at submaximal intensities.

One interesting result of this study is the variability of power output observed in all subjects. This result is in agreement with the observations reported by Smith et al. (19) during the World Cup race of Sydney in 1997 (Australia) in three triathletes. Our data support this clinical report with variability in power output fluctuating from 0 W to maximal power. During the cycling phase, it is possible to reduce energy expenditure by drafting behind other riders. Little is known about drafting in cycling and its influences on the overall performance during a triathlon (10). The first interesting report was provided by Hausswirth et al. (14), indicating that drafting during the bike course of a triathlon lowered energy expenditure, HR, and pulmonary ventilation values for a drafting distance of 0.2–0.5 m behind a lead cyclist. A global reduction of oxygen uptake (−14%), HR (−7.5%),and pulmonary ventilation (−30.8%) was reported for an average cycling speed of 39.5 $\text{km}\cdot\text{h}^{-1}$. Thus, the stochastic nature of power output and HR observed in the present study is certainly related in part to drafting and group dynamics. The high–power output oscillations measured in each subject (coefficient of variation, 55%–77%) indicate that cycling phases in Olympic distance triathlons are high-intensity activities characterized by intermittent effort. This observation is comparable with a previous report in mountain bike races (coefficient of variation, 69%) (20). In addition, the fluctuations in power output were significantly higher than the oscillations in HR observed during the same period ($P < 0.05$; Table 2). This observation is in agreement with results of previous studies comparing direct power output and HR (e.g., (20,26,27)). One reason could be the fact that regulation of HR is slower than abrupt power changes in a competition context. Indeed, when athletes choose to coast briefly, although power dropped to zero, HR cannot drop to resting values instantaneously. Thus, HR remains a useful measure of aerobic demand, and power output provides a superior indicator of immediate changes in energy demands and, especially, the demands on anaerobic metabolism.

In this study, a significant effect of period was observed for all dependant variables, except for cadence. The highest power output and HR values were observed immediately in the initial phase. Similar results have been observed in mountain biking (16,20). In these competitions, this is not surprising as the initial phase, unlike than for road stage race, is crucial for overall performance (16,20,24,25). During an Olympic distance triathlon, the weaker swimmers cycle significantly faster during the first part of cycling than the faster swimmers to catch up to the leading athlete(s) and thus draft behind them, and in the same way, the better swimmers attempt to break away to avoid being drafted (25). Our data support these observations with higher power output during the first two laps in comparison to the mean power output of the race (+11%, $P < 0.05$) and an average value of 94% of HR_{max} during the postswim phase (L1–L2). After this initial intense phase, power output and HR decrease during the race. The decline of 3.6% in bike speed observed between the postswim phase (L1–L2) and the late phase (L5–L6) is comparable with previous video reports in elite female triathletes (24). In our study, using direct output measurement, this pacing strategy is observed in all subjects and reflects a concomitant decline of 20% in PO. The difference between speed and power decline could be explained by the exponential relationship between theses dependent variables but also evidence a better skill to be sheltered behind riders inside the bike packs (i.e., pelotons). Within this framework, the potential benefits of drafting is evident. For example, in a previous study without drafting, it has been observed that, for the same speed (38 $\text{km}\cdot\text{h}^{-1}$), the mean power output was 312 W when compared with the mean power of 230 W recorded in this study (9). In Olympic distance triathlon, pacing strategies during cycling are related to the multievent characteristics of this sport. At the end of the swim, the athletes are spaced apart, and this probably influences the number of athletes who are able to form a peloton, and the work required by each athlete to reach the leading pack(s) is different than for isolated subjects. It has been reported that the number of athletes included in the group will increase the average speed of the pack and allow individual athletes to spare more energy (3). On the opposite before the cycle to run transition, the number of packs is stabilized (24). Thus, the athletes' organization within the pack allows them to decrease the workload sustained for a given speed. From a performance-optimization standpoint, anecdotal reports from triathletes highlight the transition from cycling to running as the tougher of the two transitions in a triathlon event. The first experimental studies using constant power output exercise have suggested that performance could be improved when athletes are able to run as well as possible immediately after the cycling leg (15). To the best of our knowledge, only two studies have examined the physiological effects of an exercise protocol involving stochastic power output on subsequent running performance (9,21). Suriano et al. (21) have observed during a variable cycling protocol that decreasing power during the last 5 min of the ride leads to an increase in running performance. Furthermore, when athletes try to increase power output at the end of the cycle part to come into the transition area in the best position, a significant decrease in running time was observed (9). Therefore, in the present study, possibly triathletes have diminished power output volitionally either to prepare for the subsequent running part or to reduce fatigue.

During the race, no cadence variation was observed with a mean value (91 ± 5 rpm) slightly higher than those previously reported in professional road cyclists (27) during flat (87 ± 14 rpm), semimountainous (86 ± 14 rpm), or mountainous rides (81 ± 15 rpm) and in long-distance triathletes (85 ± 7 rpm) (2). In our study, the stability of the cadence is related to a progressive decrease in distance per pedaling cycle and power output within the laps (Table 2). This indicates that the reduction in power is primarily due to a reduction in force or torque and that athletes simply choose appropriate gearing to maintain their preferred cadence. These results confirm that triathletes prefer to adopt a high pedaling cadence with an appropriate gearing to get out quickly on the run. Despite the lack of data concerning the starting run velocity, these observations are in agreement with previous results (8) in which a significant increase in running speed was observed, during the first 500 m of a 3000-m run, after the 80- and 100-rpm run sessions versus 60-rpm run session. Therefore, we could suggest that, in Olympic distance triathlon, subjects choose a strategy to reduce torque to maintain their preferred cadence at the end of the cycle part to maximize the subsequent running performance.

To our knowledge, this study is the first to describe exercise intensity during an Olympic distance triathlon. During laboratory testing, the ventilatory thresholds, maximal aerobic power, and maximal anaerobic power output have been assessed and used as reference values to identify individual workload during the race. We have reported that 51 ± 9% of the cycling time was spent in zone 1, 17 ± 6% in zone 2, 15 ± 3% in zone 3, and 17 ± 6% in zone 4, indicating that 32% of the race time was spent above intensities corresponding to V_{T2}. Our results could be compared with previous studies during cycling competitions (12,20,26). For example, in women's World Cup road cycle racing, the riders spent 51%, 17%, 12%, and 20% during flat and 52%, 22%, 13%, and 13% of total race time during hilly races in the four intensity zones assessed during laboratory testing, respectively (12). Similarly, Vogt et al. (26) have reported that, in professional road cycling, the time spent in the different intensities was 58% for zone 1, 14% for zone 2, and 28% at intensities higher than an increase of 1 $\text{mmol}\cdot\text{L}^{-1}$ above the lactate threshold (zone 3). Furthermore, in this previous study, a difference was observed between exercise intensity determined through classic HR measurement and direct measurement of power output. These authors indicate that the use of HR underestimated time spent in zones 1 and 3 and overestimated time spent in zone 2. Our results are similar for zones 1 and 2 with an underestimation of time spent in zone 1 (−47%) and an overestimation of time spent in zone 2 (+52%). On the opposite from HR measurement, we have observed an overestimation of time spent in zone 3 (+50%), but in agreement with Vogt et al. (26), the differences between intensities determined using HR and direct power output indicate that describing exercise intensity with HR measurement does not reflect precisely pacing strategies, and thus, monitoring direct power output could be more suitable to quantify the absolute intensity of a race or to control training for these particular events. However, recording HR remains of interest in quantifying the relative intensity of exercise, as with fatigue, a similar power output could correspond to a higher energy demand.

This study indicates that anaerobic power and capacity may be important for meeting the physiological demands of Olympic distance triathlon racing because a significant part of the race corresponds to intensities above MAP. Classically, triathlon racing has been mainly described as an endurance event, and to date, very few data using blood lactate measurements concerning the anaerobic demand of this event in elite triathletes are available (9,14). Our data, mixing female and male athletes, determined a relative maximal anaerobic power of 12.9 $\text{W}\cdot\text{kg}^{-1}$. In this study, direct measures of power output show high variations of power output, with values above 60% of MAnP (489 ± 103 W) during hill or "technical" bike sections. In an attempt to break up groups of drafting athletes, the triathletes complete rapid accelerations in supramaximal power output interspersed with periods of submaximal exercise. In this study, 57 cycling periods of seven consecutive seconds and 13 periods of 15 s were registered at an intensity above 100% of maximal aerobic power. Furthermore, 13 periods of seven consecutive seconds (included in the 57 periods) were observed for intensities higher than 60% of MAnP. A higher power output (>100% MAP) was required during the initial cycle phase (L1–L2, 20 ± 6% of total cycling time), and the average time spent above MAP during this race (17 ± 5%) suggests a significant contribution of anaerobic metabolism to the energy requirements of the cycling phase in a triathlon. Therefore, in contrast to individual time trials as in an Ironman, the energetic demand of an Olympic distance triathlon is similar to previous reports during professional cycling events with repeated bouts of exercise approaching or exceeding $\dot{V}O_{2\max}$ (18).

In conclusion, this study indicates that subjects progressively reduced speed, power output, and HR during the event. This decrease in intensity was coupled with an increase in the variability of these measurements. Also important is that Olympic distance triathlon requires a higher aerobic and anaerobic involvement than constant-workload cycling exercise classically analyzed in laboratory settings or Ironman triathlons. The performance profile of the race is characterized by high–power output bursts during short periods because the cycling phase in Olympic distance triathlon requires the ability to sprint or to push for a better position in the peloton to cope with the race strategy. Furthermore, the decrease in power output at the end of the cycle portion of the triathlon part could be related to a strategy to prepare for the subsequent running part. Further investigations should analyze the importance of anaerobic power improvement for overall performance and the effect of specific cycle strategies on running performance.

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