Physiology International 109 (2022) 3, 427–442
DOI: 10.1556/2060.2022.00181

AKADÉMIAI KIADÓ

Intensified training before Olympic-distance triathlon in recreational triathletes: "Less pain, more gain"

XABIER ZARRANZ-DOMENCH[1], IBAI GARCIA-TABAR[2,3]*, JUAN C. LIZARAZU[1], MAITE RUESTA[1] and ESTEBAN M. GOROSTIAGA[1]

[1] Studies, Research and Sports Medicine Center (CEIMD), Government of Navarre, Pamplona, Spain

[2] Department of Physical Education and Sport, Faculty of Education and Sport, Society Sports and Physical Exercise Research Group (GIKAFIT), University of the Basque Country (UPV/EHU), Vitoria-Gasteiz, Spain

[3] Biobara, Vitoria-Gasteiz, Spain

Received: October 18, 2021 • Revised manuscript received: April 7, 2022 • Accepted: April 27, 2022
Published online: August 24, 2022

ABSTRACT

Objectives: To examine 1) the contribution of physiological performance variables to Olympic-distance (OD) triathlon performance, and 2) the links between an 8-wk intensified training plus competition preceding the main OD triathlon race and the changes in the physiological status in triathletes. *Study Design:* An observational longitudinal study. *Methods:* Endurance performance variables during maximal incremental running and cycling tests, and average velocity during an all-out 400-m swimming performance test (V_{400}) were assessed before (T1) and after (T2) the intensified training in 7 recreational-level triathletes. *Results:* Overall main OD triathlon time was extremely largely ($r = -0.94$; $P = 0.01$) correlated with peak running velocity (PRV). Best correlation magnitude between exercise modes' partial race times and the corresponding specific physiological criterion tests was observed for swimming ($r = -0.97$; $P < 0.001$). Improvement in V_{400} (2.9%), PRV (1.5%) and submaximal running blood lactate concentration (17%) was observed along the training period, whereas no changes were observed in the cycling endurance performance variables. Higher volume of training plus competition at high intensity zones during cycling, running and swimming were associated with lower improvements or declines in their corresponding exercise mode-specific criterion performance variables ($r = 0.81$–0.90; $P = 0.005$–0.037).

* Corresponding author. Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country (UPV/EHU), Portal de Lasarte, 71, 01007 Vitoria-Gasteiz, Spain. Tel. +34 945 01 35 07.
E-mail: ibai.garcia.tabar@gmail.com, ibai.garcia@ehu.eus

Conclusion: Results indicate that: 1) PRV is highly associated with overall OD triathlon performance, and 2) spending much time at high relative intensities during swimming, cycling or running may lead, in a dose-response manner, to lower improvements or decreases on those exercise-specific physiological performance variables. This may favor the emergence of overreaching or diminished performance.

KEYWORDS

aerobic training, exercise testing, physical fitness, training load monitoring, exercise prescription, endurance performance prediction

INTRODUCTION

Olympic-distance (OD) triathlon is a sport sequentially linking a 1500-m swim, a 40-km draft legal cycling, and a 10-km run. Previous studies have reviewed the physiological demands of triathlon racing and the physiological characteristics of triathletes of different competitive levels [1–6]. To date, however, only one study attempted to predict overall and split OD triathlon times by specific physiological swimming, cycling or running test results in recreational-level triathletes [7]. Since the publication of this study more than 20 years ago much has changed in OD triathlon [8]: nutrition strategies, training and pacing strategies, and equipment among others. Besides, drafting is allowed. As a result, OD triathlon demands have been changed and overall as well as split race performances have improved [8]. Those modifications may have altered the different contributions of each physiological testing performance variable to OD triathlon performance. It is therefore time to investigate whether these changes have altered the relationships between the values of the specific physiological tests and the OD triathlon performance in recreational-level triathletes.

On the other hand, longitudinal observational training studies in recreational-level OD triathletes are scarce [8]. However, they are of interest due to the extremely large number of participants worldwide (4 million) [9] and because recreational-level triathletes' training and competition volume ($\sim$5 $h \cdot wk^{1}$) usually differs from that of national or international-level OD triathletes ($\sim$10–20 $h \cdot wk^{1}$) [10]. Furthermore, recreational-level triathletes usually tend to abruptly increase the volume of their training plus competition (from $\sim$5 $h \cdot wk^{1}$ to $\sim$8 $h \cdot wk^{1}$) during the 8–12 weeks preceding their main race, whereas elite triathletes have a tendency to decrease their training volume during the same time frame [10]. The links between training and the changes in the specific physiological test results during the intensified training period before the main race in recreational-level OD triathletes has yet to be characterized [8]. Several studies have shown that intensified training periods may generate excessive sympathetic stress, delayed recovery of the autonomic nervous system [11], and incomplete recovery of basal muscle glycogen levels [12], favoring the emergence of overreaching, overtraining or diminished performance [13]. Therefore, results of the examination of the associations between training and the changes in the physiological status of this type of triathletes might interest recreational endurance athletes and their coaches.

Accordingly, the purpose of this study was two-fold: 1) to determine whether the selected physiological variables are related to overall or split OD triathlon performance in recreational triathletes, and 2) to assess the relationships in those same participants between the training and competition times performed at different intensity zones during 8 wks of intensified training plus competition preceding the main race and the changes in their physiological status.

We hypothesized that 1) the physiological criterion variables would be highly correlated with overall and specific split OD triathlon times, and 2) the increase in training volume and intensity during 8 weeks would be related to positive changes in the physiological test results in a dose-response manner.

MATERIALS AND METHODS

Study design

In this observational longitudinal study, recreational-level triathletes' training and competition were monitored throughout an 8-wk intensified training plus competition period preceding an official OD triathlon race, the main competitive goal of the season. Before the study, all participants took part in a 5-month general training. Criterion performance measures during maximal running and cycling as well as during an all-out 400m swimming (V_{400}) test were assessed during the 2.5 wks. immediately preceding the study (T1) and 5–12 days after (T2) the completion of the race [14]. Training plus competition load of all participants was carefully monitored throughout the entire study by their coach. Thus, it was possible to examine the influence of an 8-wk intensified training period on physical standard tests and competition performance time.

Participants

Seven (one female) motivated, well-trained, recreational-level triathletes, members of the same local triathlon club, and trained by the same coach, participated in this study. Their mean (±SD) age, body mass and height were 34 ± 6 years (range: 22–44), 71.5 ± 8.4 kg and 175 ± 1 cm, respectively. Their performance over the main OD triathlon race in the previous year was 2 h 56 min ± 2 min (range: 2 h 21 min to 2 h 56 min). All participants had regularly competed in triathlons for at least 2 years (average: 5 ± 3.5 years) and were regularly training ~5 $h \cdot wk^1$ over the last 5 months preceding this experimental period. Further inclusion criteria were 1) having a training routine of ≥3 aerobic training sessions per week; 2) availability to complete the 3-day testing protocol before (T1) and after (T2) the training period and to compete in the same official OD triathlon race, and 3) commitment to regularly train during the intensified 8-wk training period using the training zones established at T1 and implemented in their personal training-devices with access to the coach. Exclusions criteria were 1) taking any medication/supplement that could affect the results of the study, 2) having any known cardiovascular, respiratory or circulatory dysfunction, and 3) impossibility to meet any of the above described inclusion criteria.

The participants were informed about the experimental procedures in detail. Procedures were approved by the Local Institutional Review Board and were conformed to the Declaration of Helsinki and ethical standards [15]. Participants acknowledged voluntary participation through written informed consent.

Physical standard test procedures

Testing schedule. Participants were familiarized with the testing protocol. For both T1 and T2 testing periods, the participants completed a 3-d experimental protocol. Participants arrived to each testing session in a rested state, at least 2 h postprandial. Participants were asked to replicate diet and exercise regimens the 2 days preceding each testing session to limit fluctuations of initial glycogen concentration between trials. During the first-day testing-session of each testing period, participants were subjected to a maximal incremental running test. Maximal incremental cycling tests were performed in the second testing sessions. In the third-day testing sessions, participants performed the V_{400}. Testing was integrated into weekly training schedules. Participants were vigorously encouraged by their coach to complete exhaustion. In previous assessments in our laboratory, inter-test reliability of maximal incremental tests and anthropometric measurements has shown test-retest intra-class correlation coefficients of >0.91.

Maximal incremental running test. Participants performed a maximal incremental running test on a treadmill (Kuntaväline, Hyper Treadmill 2040, Finland) with the gradient set at 1%. Initial speed was 7 $km \cdot h^{-1}$, and was increased by 1 $km\,h^{-1}$ every minute. At the end of the stage of 14 (2 participants) or 15 $km \cdot h^{-1}$ (5 participants) (i.e. at the mean stage velocity of 14.7 $km \cdot h^{-1}$) capillary whole-blood samples for blood lactate concentration (BLC) measurements were obtained during a 30-s rest period.

Maximal incremental cycling test. The maximal cycling test was performed on a computer-controlled cycle-ergometer (SRM High Performance Ergometer Ingenieurbüro Schoberer, Germany). Initial power was 60 W and was increased by 30 W every minute. Ten seconds before the end of the submaximal stages of 210 and 270 W capillary whole-blood samples were obtained for BLC measurements in every participant. Triathletes were instructed to maintain a constant cycling pedaling cadence of 80 $rev \cdot min^{-1}$.

Both laboratory running and cycling tests were performed under temperature (22.3 ± 1.4 °C), humidity (33 ± 4%) and luminosity controlled conditions. The capillary whole-blood samples were obtained from hyperaemized earlobes, and BLC was amperometrically determined (Lactate Pro 2 LT-170; Arkray KDK Corporation, Shiga, Japan). Heart rate (HR) (Polar Electro Oy, M400, Finland) was monitored throughout both maximal tests. Maximal HR (HR_{max}) either during running (HRR_{max}) or cycling (HRC_{max}) was considered the highest HR recorded. Peak running velocity (PRV) and peak cycling power (PCP), as well as the velocity (V_{90}) and power (P_{90}) associated with 90% of HRR_{max} and HRC_{max}, respectively, were determined as previously described [16].

400-m swimming test. Participants performed, one by one, wearing non-neoprene swimsuit, an all-out 400-m swimming performance test from a push start in a 25-m indoor swimming pool (26–27 °C). Time was recorded using a stopwatch, and the average velocity of the test (V_{400}) computed for further analyses.

Training plus competition data analysis

The same training plan with the same training load was delivered to each participant for the 5 months preceding the beginning of the study, as well as for the 8-wk intensified training period. Attending to the observational study design, no further instructions were given to the participants. Triathletes recorded their day-to-day training and competition data during the 8-wk study period in HR monitors (Polar Electro Oy, Kempele, Finland, Garmin International, Kansas, USA or Suunto Oy Vanta, Finland) for running and cycling activities. Swimming training time and distances were recorded by training logs. The training plus competition load recorded for each session included total time and distance distributed across exercise modes (swimming, cycling and running) and intensity zones. The intensity distribution is classified in a 5-zone model expressed either as a percentage of HR_{max} (cycling and running) or V_{400} (swimming) [17, 18]. A binary model with zones 1 and 2 as light intensity training (LIT) and zones 3 to 5 as high intensity training (HIT) was also used. Table 1 presents both intensity-zone models.

The main OD triathlon race was held on the 3rd of June 2018 and consisted of a 1.5-km swim in a lake-reservoir, a 40-km cycling course, and a 10-km run course. During the swimming stage the participants wore neoprene wetsuits. The road bike, in which drafting was allowed, consisted of completing two laps on a 20 km long circuit including 3 uphill sections per lap: a) 3.8 km long, average slope of 2%, b) 2.8 km long, average slope of 1.7%, and c) 2.9 km long, average slope of 1.3%. Mean ambient temperature was 22.6 °C (range: 19.3–23.6 °C).

Statistical analysis

Standard statistical methods were used for the calculation of means, standard deviations (SDs), standard errors of the estimates (SEEs) and confidence intervals (CIs). Data were analyzed using parametric statistics following confirmation of normality (Kolmogorov–Smirnov test), homoscedasticity (Levene's test) and, when appropriate, sphericity (Mauchly's test). The $P < 0.05$ criterion was used to establish statistical significance. Significance levels, however, should be viewed as descriptive, not definitive. Student's paired *t*-tests were used to evaluate differences between T1 and T2. The magnitudes of the differences were assessed using 90% CIs and Hedges' *g* effect sizes (ES) [19]. Differences in time spent at LIT and HIT at the different exercise modes (swimming, cycling, and running) and along the 8-wk training period at 2-wk intervals were analyzed using two-factorial repeated measures ANOVA with Bonferroni correction for multiple comparisons. Linear regression analyses with *Pearson*'s product-moment correlation coefficients (r) were used to determine the direction and magnitude of the relationships. Evaluation of Cook's distance revealed minimal influence of the individual data points on the correlation magnitudes [20]. Assuming a power of 80% and a type I error of 0.05 for a minimum value of a very large correlation ($r = 0.80$), the post-hoc estimated sample size required to accomplish this study is 7 triathletes. The correlation magnitudes and ES values were interpreted as described elsewhere [21]. Analyses were performed using IBM SPSS Statistics 22 (IBM Corporation, USA). Descriptive statistics are reported as means (±SD).

RESULTS

Physical standard tests' results

Table 2 summarizes the results of anthropometric and physical standard tests. Swimming V_{400} increased by 2.9%. Concerning running test results, HRR_{max} remained unaltered, PRV and V_{90} increased by 2–3% and BLC decreased by 17%. Cycling maximal and submaximal physiological variables remained unaffected over the intensified training period.

Training plus competition data

Participants completed 86 ± 17% (range: 82–119) of the originally planned sessions. Table 3 shows the number of training plus competition sessions and rest days, as well as the distance and time spent at each exercise mode during the 8-wk period. The cumulative total duration of training plus competition over the 8 weeks preceding the main race ($7.7 \pm 1.6\ h \cdot wk^{-1}$; range 5.9–10.5) was 51%

Table 1. The 5-zone and binary intensity scales used in the current study for swimming, cycling and running training and competition

Intensity Zone (Z)	Swimming Velocity ($\%V_{400}$)	Cycling Heart Rate ($\%HRC_{max}$)	Running Heart Rate ($\%HRR_{max}$)	Binary model
Z5	>95	>94	>94	HIT
Z4	89–94	89–93	89–93	
Z3	86–88	84–88	84–88	
Z2	84–85	74–83	74–83	LIT
Z1	≤83	54–73	54–73	

$\%V_{400}$: swimming velocity expressed as a percentage of the average velocity of the initial all-out 400-m swimming test; *$\%HRC_{max}$*: heart rate expressed as a percentage of the maximal heart rate recorded during the initial cycling test; *$\%HRR_{max}$*: heart rate expressed as a percentage of the maximal heart rate recorded during the initial running test; *HIT*: high intensity training zone; *LIT*: low intensity training zone.

Table 2. Anthropometric and physical standard test results before (T1) and after (T2) the intensified 8-wk training period ($n = 7$)

	T1	T2	Δ (%T1)	90% CI			ES	*P*
Anthropometry								
Body mass (kg)	71.5 ± 8.4	71.7 ± 8.4	0.3	−1.27	to	0.92	0.02	0.77
Body fat (%)	11.3 ± 3.1	11.6 ± 3.6	2.0	−0.94	to	0.34	0.09	0.41
Running								
PRV ($km \cdot h^{-1}$)	19.4 ± 1.5	19.7 ± 1.4*	2.0	−0.59	to	−0.15	0.26	0.02
V_{90} ($km \cdot h^{-1}$)	15.6 ± 0.9	16.1 ± 1.4*	3.3	−0.92	to	−0.18	0.50	0.03
$BLC_{14.7}$ ($mmol \cdot L^{-1}$)	2.4 ± 0.4	2.0 ± 0.2*	−12.2	0.09	to	0.56	1.06	0.03
$HR_{14.7}$ ($b \cdot min^{-1}$)	159 ± 6	156 ± 8	−2.0	0.01	to	5.42	0.42	0.09
HRR_{max} ($b \cdot min^{-1}$)	179 ± 5	180 ± 7	0.7	−4.59	to	2.02	0.20	0.48
Cycling								
PCP (W)	383 ± 53	370 ± 55	−3.4	−5.34	to	32.05	0.24	0.21
P_{90} (W)	302 ± 50	294 ± 53	−2.5	−6.86	to	22.41	0.15	0.34
BLC_{210} ($mmol \cdot L^{-1}$)	1.8 ± 0.5	1.9 ± 0.7	4.2	−0.30	to	0.10	0.17	0.37
BLC_{270} ($mmol \cdot L^{-1}$)	3.1 ± 1.3	2.9 ± 1.2	−3.3	−0.39	to	0.79	0.16	0.53
HR_{210} ($b \cdot min^{-1}$)	138 ± 15	136 ± 19	−1.7	−2.25	to	6.54	0.13	0.38
HR_{270} ($b \cdot min^{-1}$)	160 ± 14	160 ± 14	−0.3	−3.12	to	3.97	0.03	0.82
HRC_{max} ($b \cdot min^{-1}$)	178 ± 4	176 ± 8	−1.2	−2.55	to	6.83	0.35	0.41
Swimming								
V_{400} ($m \cdot s^{-1}$)	1.02 ± 0.14	1.05 ± 0.15*	2.1	−0.04	to	−0.01	0.15	0.03

Δ: change from T1 to T2; *90% CI*: 90% confidence intervals; *ES*: effect size; *PRV*: peak running velocity; *V_{90}*: velocity associated with 90% of maximal heart rate; *$BLC_{14.7}$*: blood lactate concentration (BLC) at 14.7 $km \cdot h^{-1}$; *$HR_{14.7}$*: heart rate (HR) at 14.7 $km \cdot h^{-1}$; *HRR_{max}*: maximal running HR; *PCP*: peak cycling power; *P_{90}*: power associated with 90% of maximal HR; *BLC_{210}*: BLC at 210 W; *BLC_{270}*: BLC at 270 W; *HR_{210}*: HR at 210 W; *HR_{270}*: HR at 270 W; *HRC_{max}*: maximal cycling HR; *V_{400}*: average velocity during an all-out 400-m swimming test.
(*) *P* value <0.05 with moderate to very large ES.

Table 3. Number of sessions and rest days, and distance and time spent at training plus competition during the 8-wk experimental training period ($n = 7$)

	Total	Per week
Training sessions (no.)	52 ± 10	6.6 ± 1.2
Rest days (no.)	13 ± 4.5	1.7 ± 0.5
Distance (km)		
Swimming	29 ± 7.8	3.6 ± 0.9
Cycling	860 ± 268	107.5 ± 31.1
Running	195 ± 41	24.4 ± 4.8
Duration (h)		
Swimming	11.8 ± 2.4	1.5 ± 0.3
Cycling	33.5 ± 7.7	4.2 ± 1.0
Running	16.8 ± 4.5	2.1 ± 0.7
Sum	62.1 ± 13.1	7.7 ± 1.6

greater than the average weekly duration of training plus competition carried out during the previous 5 months. Divided into exercises modes, this corresponds to a 60% increase in swimming, a 147% increase in cycling and a 7% reduction in running time. These training time increment differences among disciplines were mainly due to climatology conditions during winter that did not allow cycling at the early stages of the training, and the preparation of duathlons during the beginning of the competitive season. Including the main OD triathlon competition, during the 8-wk experimental period the participants competed in 3.3 ± 1.7 (range: 2–7) Triathlon (Super Sprint, Sprint, Olympic and Middle-distance) or Duathlon (Sprint and Standard distance) competitions. The average competition time during this period was 7.8 ± 3.6 h.

Figure 1A shows the mean total training plus competition time spent at each intensity zone (Z1 to Z5) in each exercise mode over the 8-wk training period. Total times at LIT were substantially higher in cycling compared to swimming ($P < 0.001$; 90% CI: 957 to 1,630; ES: 4.40) and running ($P < 0.001$; 90% CI: 752 to 1,330; ES: 6.04). There were no differences in the total time at HIT among exercise modes ($P > 0.05$; ES: 0.18–0.23).

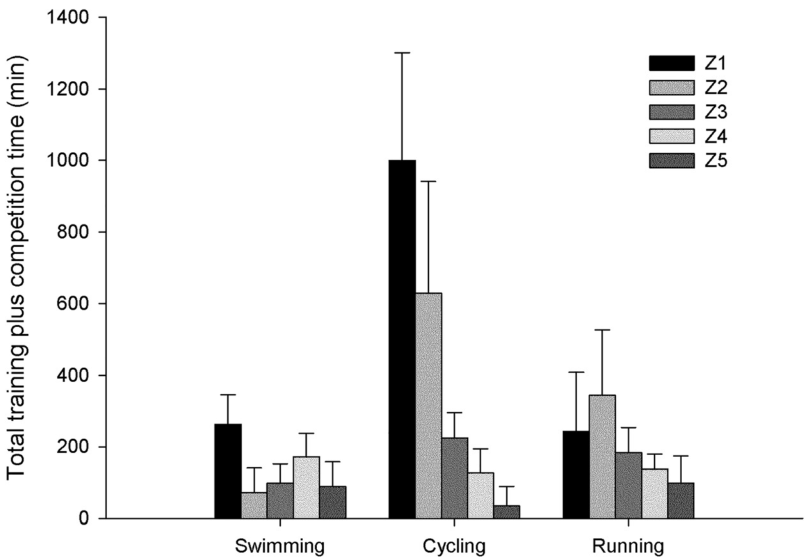
Figure 1B shows the mean total training plus competition time spent at LIT and HIT zones distributed every 2 weeks. The relative contribution of LIT for swimming, cycling and running was 51, 82 and 58%, respectively. Training plus competition time at LIT tended to be lower at weeks 7–8 compared to weeks 3–4 (−23%; $P = 0.13$; 90% CI: −18 to 354; ES: 0.85).

Main OD triathlon performance

One participant did not complete the OD race due to a breakdown of the bicycle, but was included in the rest of the study analyses. Performance times to complete each exercise mode during the main OD triathlon were 28.4 ± 3.6 min (range 22.6–31.5), 1h 32 min 24s ± 8.5 min (range 1 h 18 min 24 s – 1 h 42 min 18 s) and 47.4 ± 4.8 min (range 40.8–52.0) for the swimming, cycling and running stages, respectively. Total average race time was 2 h 49 min ± 15 min (range 2 h 22 min – 3 h 03 min).

Figure 2 reports time distribution across intensity zones during the cycling and running segments of the OD triathlon race. Time spent at HIT was 75 and 88% for cycling and running, respectively.

A



B

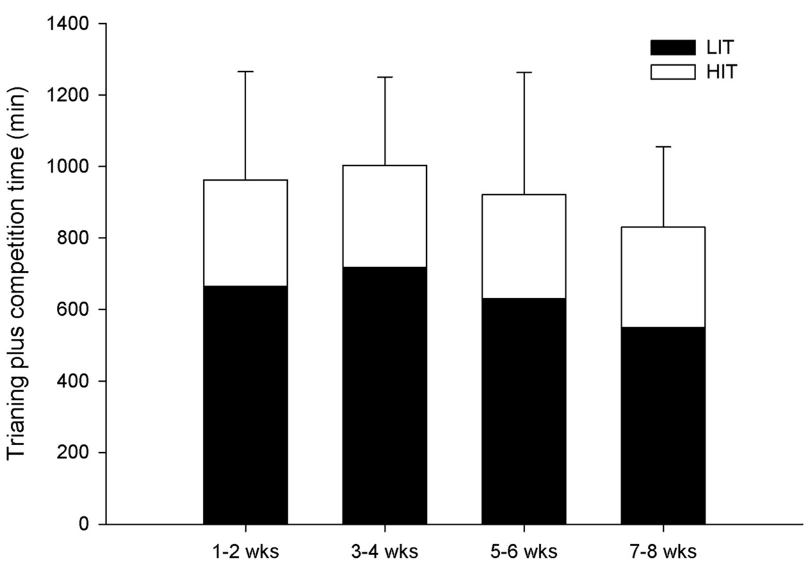


Fig. 1. Mean (SD) training plus competition time spent at swimming, cycling and running at each intensity zone (Z1 to Z5) over the 8-wk training period (A), and mean total training plus competition time spent at light intensity (LIT; i.e. Z1 + Z2) and high intensity training (HIT; i.e. Z3+ Z4 + Z5) zones distributed every 2 weeks (B)

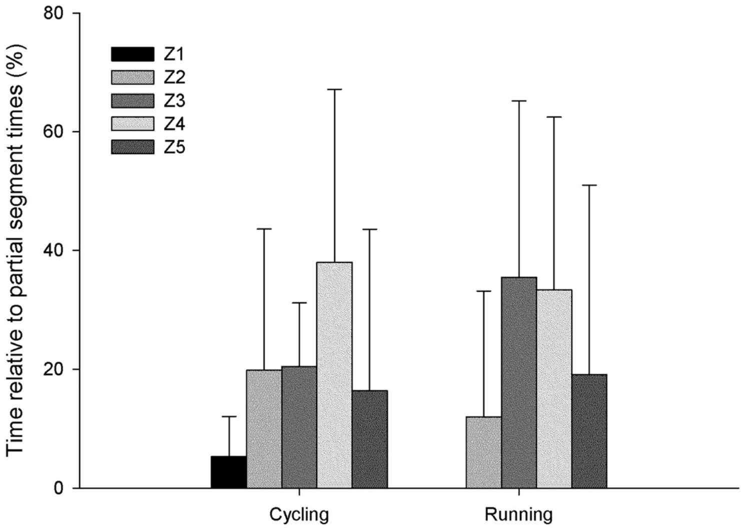


Fig. 2. Mean (SD) time spent at each intensity zone in cycling and running during the main Olympic Distance Triathlon race by the participants who completed the race (n = 6)

Table 4. Pearson's correlation magnitudes between the selected maximal and submaximal physiological standard performance markers with the main Olympic-distance triathlon split and overall race times (n = 6)

	Swimming time (min)	Cycling time (min)	Running time (min)	Overall race time (min)
Swimming				
V_{400} (m s^{-1})	−0.966***			−0.825*
Cycling				
PCP (W)		−0.625		−0.524
PCP/BM ($W \cdot kg^{-1}$)		−0.880*		−0.832*
P90/BM ($W \cdot kg^{-1}$)		−0.954**		−0.931**
BLC_{210} ($mmol \cdot L^{-1}$)		0.193		0.001
BLC_{270} ($mmol \cdot L^{-1}$)		0.071		0.001
Running				
PRV ($km \cdot h^{-1}$)			−0.813*	−0.944**
$BLC_{14.7}$ ($mmol \cdot L^{-1}$)			0.676	0.615
V_{90} ($km \cdot h^{-1}$)			−0.631	−0.707

V_{400}: average velocity during an all-out 400-m swimming test; *PCP*: peak cycling power; *PCP/BM*: PCP relative to body mass; *P90/BM*: power associated with 90% of maximal heart rate (HR) relative to body mass; *BLC_{210}*: blood lactate concentration (BLC) at 210 W; *BLC_{270}*: BLC at 270 W; *PRV*: peak running velocity; *$BLC_{14.7}$*: BLC at 14.7 $km \cdot h^{-1}$; *V_{90}*: velocity associated with 90% of maximal HR.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

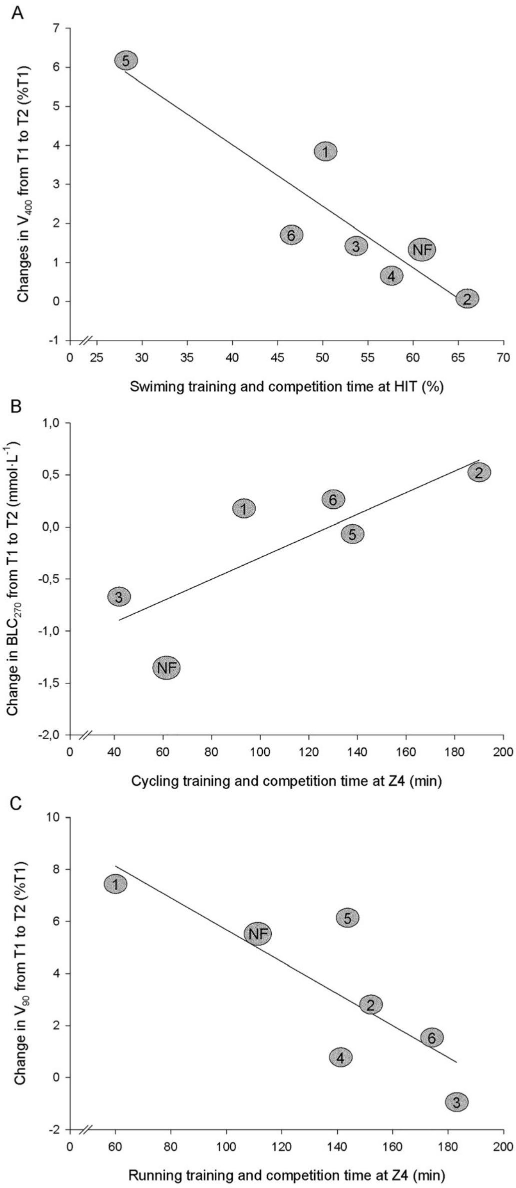


Fig. 3. Relationships between training plus competition time spent at HIT during swimming (A) or Z4 during cycling (B) and running (C) with changes from T1 to T2 observed in the average velocity during an all-out 400-m swimming test (V_{400}) (A), blood lactate concentration (BLC) at 270 W (B) and velocity associated with 90% maximal heart rate (V_{90}) (C). Numbers indicate the relative rank order achieved by each subject during the main OD triathlon race with respect to the other subjects who completed the study. NF: subject who did not finish the race

Relationships between the physical tests and performance during the main OD triathlon (Table 4)

PRV was *extremely largely* correlated to overall OD triathlon time. The magnitude of this correlation was slightly higher than that observed for cycling $P_{90}\cdot BM^{-1}$ and swimming V_{400}. Concerning split times, V_{400} was *extremely largely* correlated with its corresponding specific exercise mode split time, closely followed by cycling $P_{90}\cdot BM^{-1}$. PRV was *very largely* correlated with running finish time, although the magnitude of the correlation was the lowest of all three.

Relationships between training plus competition time and changes in the physical tests

Figure 3 illustrates the strongest correlations observed between the assessed physiological variables and the time spent during training and competitions at different intensity zones. Very large to extremely large relationships were observed between swimming, cycling and running training plus competition volume performed at HIT or Z4 with the changes from T1 to T2 in swimming V_{400} ($r = -0.90$; $P = 0.005$; SEE = 1.01; 95% CI: −0.24 to −0.07; $n = 7$) (Fig. 3A), cycling submaximal blood lactate concentration ($r = 0.84$; $P = 0.037$; SEE = 1.39; 95% CI: −0.01 to 0.07; $n = 6$) (Fig. 3B), and running V_{90} ($r = -0.81$; $P = 0.027$; SEE = 2.00; 95% CI: −0.11 to −0.01; $n = 7$) (Fig. 3C), respectively. Interestingly, no relationship was observed between time spent at HIT (swimming) or Z4 (cycling and running) during the main OD triathlon and the changes in the corresponding specific physiological tests ($P > 0.05$).

DISCUSSION

Despite the limitations, the main results of our study were threefold. 1) According to our first hypothesis, laboratory PRV best correlated with overall OD triathlon performance whereas field V_{400} best correlated with its specific swimming split OD race time. 2) A 52% increase, up to 8 $h\cdot wk^{-1}$, of training plus competition during the 8 weeks preceding the main race resulted in positive swimming and running, but not cycling, adaptations to the physical standard tests. 3) In disagreement with our second hypothesis, individual times devoted to training plus competition at HIT zones in each discipline during the 8-wk experimental period were inversely related to individual changes in the corresponding specific physiological tests.

Relationships between physiological variables and overall OD triathlon times

PRV best predicted ($r = -0.94$) overall OD triathlon time, closely followed by $P_{90}\cdot BW^{-1}$ and V_{400} (Table 4). $P_{90}\cdot BW^{-1}$ better correlated with overall race time than PCP or $PCP\cdot BW^{-1}$. The reason why $P_{90}\cdot BW^{-1}$ better predicted OD performance than P_{90} is probably due to the hilly course topography of the cycling sector, which substantially increases the influence of body weight on cycling performance [22]. The lower magnitude of association found between V_{400} and overall race time may probably be a result of the swim stage being only about 17% of total race time. These results are in agreement with previous research showing that in relatively homogeneous groups of recreational [7, 23], national [2] or elite level [24] triathletes total OD triathlon time is inversely related to running maximal oxygen uptake ($\dot{V}O_{2max}$) and PRV, cycling $\dot{V}O_{2max}$ and PCP, and flume-pool swimming and V_{400} ($r = -0.71$ to -0.94). The higher association found for the running testing variables agrees with studies showing that the running split is the most influential in overall race time [2, 7, 24, 25], indicating the importance of this exercise mode for the overall OD performance [26]. However, other authors failed to relate maximal swimming or arm ergometer, cycling, and running standard physical test results with overall OD triathlon performance time in very homogeneous groups of national [3, 27] and elite [27] level triathletes. The reasons of these discrepancies may be due to differences in gender, sample size, group variability (e.g. the original branch of sports of the participants), participants' performance level, race strategy, swimming or cycling in drafting positions or responses to race variables, such as hills, heat or the number of sharp curves.

Relationships between physiological variables and split OD triathlon times

The best correlation magnitude between the physiological standard test variables with their respective split times during the main OD race was found for V_{400} ($r = -0.97$), followed by $P_{90} \cdot BW^{-1}$ ($r = -0.96$) and PRV ($r = -0.81$) (Table 4). This finding is in concordance with investigations performed with relatively very homogeneous small numbers ($n = 8$–17) of recreational- to national-level OD triathletes [2, 3, 7]. These investigations reported, with respect to their exercise mode specific split times, higher correlations for swimming V_{400} or cycling $\dot{V}O_{2max}$ and PCP, than for running $\dot{V}O_{2max}$ or PRV. The main reason explaining why the magnitude of correlations decreases as the race moves forwards may be related to the cumulative fatigue effects of swimming and/or cycling prior to the running event. It has been documented that, compared to a control isolated run, during the running segment of a prolonged sequential exercise similar to a triathlon there is a residual fatigue effect [28]. This residual fatigue effect increases the physiological demands of the running event of the race as reflected by the decrease in running $\dot{V}O_{2max}$ [29] and the increases in core temperature [4], BLC [5], HR [4, 5], rate of perceived exertion [4], stride rate [30], and cost of running [5, 30] observed during the running segment. The degree of this residual fatigue may greatly differ between triathletes, depending on inter-subject differences during the swim and cycling segments in tactical and dietary strategies, the ability to keep consistent relative intensity [28], swim-bike and bike-run transition times or drafting times. This inter-subject variability is probably higher in inexperienced recreational-level triathletes [4] possibly due to the different branches of sports they come from and may lead to large differences from one participant to another in their running capability impairment due to the cumulative residual fatigue [28].

Improvements in running and swimming but not in cycling tests after training

Average training plus competition time increased approximately from 5 to 8 $h \cdot wk^{-1}$ during the 8 weeks preceding the main race. Observed positive adaptations from T1 to T2 (Table 2) during submaximal and maximal running and swimming tests were therefore expected. However, no improvement was observed in the cycling performance laboratory test, even though: 1) participants spent much more time training and competing in cycling than in the other disciplines (Table 3), and 2) the training plus competition time increment from T1 to T2 devoted to cycling was the highest (147%) compared with a 60% increase in swimming and a 7% reduction in running. A lack of training-induced improvement in PCP or cycling $\dot{V}O_{2max}$ [6, 10] has already been observed in elite recreational triathletes training 13–16 $h \cdot wk^{-1}$, of which the majority (41–50%) of the training was dedicated to cycling. These data suggest that 1) in our recreational-level triathletes the potential for improvement seems to be probably greater in running and swimming than in cycling, and 2) training more time in a given discipline does not always result in positive adaptations for that given discipline. An alternative explanation may be that the intensity training distribution in the cycling training program was inadequate for improving cycling performance. Whether these non-improvements in cycling performance after an intensified training period before an OD race occur in other recreational triathletes that might come from different branches of sports is unknown and is beyond the scope of this study.

Times spent at high intensity correlated with changes in the physiological status

The reason for the ineffectiveness of cycling training in producing improvements in the cycling performance test is unknown, although it may be related to the high amount of training plus competition time completed at HIT zones. The main finding of this study was that higher volumes of training plus competition at Z4 (89–93%HR_{max}) during cycling and running or at HIT (Z3+Z4+Z5) during swimming over the 8-wk period were associated with lower improvements or declines in their corresponding exercise-mode specific criterion physical tests. Figure 3 shows that those participants training and competing between T1 and T2 on average more than ≈65% of total time at HIT zone during swimming, more than ≈2 h 00 min (≈15 $min \cdot wk^{-1}$) at Z4 during cycling, or more than ≈3 h 00 (≈23 $min \cdot wk^{-1}$) at Z4 during running, showed no increased or decreased performance in the corresponding criterion physical tests.

Several studies have shown that excessive HIT training might generate excessive metabolic acidosis [31], sympathetic stress, catecholamine depletion [32] during exercise and delayed recovery of the autonomic nervous system immediately after training [11], critically accelerating glycogen depletion [12]. This may favor the emergence of overreaching, overtraining or diminished performance [13]. Our results are consistent with those of previous studies in national standard rowers [33, 34], sub-elite regional/national class runners training 5–6 $h \cdot wk^1$ [35] and club-level Ironman triathletes training 8–12 $h \cdot wk^1$ [10, 36], suggesting that higher training volumes at moderate to HIT zones may be too demanding and detrimental in endurance athletes training >6 $h \cdot wk^1$. This supports the notion that in well-trained athletes, only a comparatively small amount of moderate to HIT training is required in order to achieve greater physiological gains and prevent overtraining [35].

Study limitations

The present study is limited in some aspects. Firstly, the sample size of the study is small ($n = 7$). A known limitation in this type of studies with well-trained athletes is the small sample size, since most often the compliance and motivation of athletes is low, typically because neither the athletes nor their coaches like to be disturbed [37]. A key factor for the successful completion of this study, in fact, was the high motivation of the participants and the coach, since the coach was an active member of our research team. Secondly, the applicability of the results is limited to a relatively homogeneous sample of recreational triathletes training 5–8 $h \cdot wk^{-1}$. Thirdly, another known limitation of the small sample size is that the *Pearson*'s product-moment correlation coefficients are more susceptible to be influenced by heterogeneity. However, evaluation of Cook's distance [20] revealed minimal influence of the individual data points on the correlation magnitudes. Finally, the investigation was a longitudinal observational study. Observational studies have limited control over confounding factors compared to interventional studies.

However, they provide information on “real world” use and practice and provide data to design more pragmatic training plans. Besides, a report from the *Cochrane Collaboration* concluded that the results of observational studies are very similar to the ones reported by similarly conducted *randomized controlled trials* [38]. Despite these significant limitations, the results of the present study 1) agree with previous studies concerning the predictor factors of OD triathlon performance, and 2) provide novel information about the links between the volume and intensity of training conducted and the changes observed in laboratory and field tests over an intensified training period.

CONCLUSION

Despite the limitations, the main results of this study show that, as expected, PRV best correlated with overall OD triathlon time, whereas V_{400} best predicted its respective split race time in recreational triathletes. During the 8-wk intensified training and competition period, the individual time devoted to training plus competition at HIT in each discipline was inversely related to individual changes in the corresponding specific physical criterion tests. This suggests that in this population, spending on average more than ≈65% of total time at HIT zone during swimming, more than $\approx 15\,\text{min}\cdot\text{wk}^{-1}$ at Z4 during cycling, or more than $\approx 23\,\text{min}\cdot\text{wk}^{-1}$ at Z4 during running, might potentially be associated with detrimental effects in a dose-response manner. Further longitudinal studies using larger sample sizes are needed to confirm the present results and to optimize training intensity and volume preceding the main race of the season in well-/trained recreational triathletes.

Conflict of interest: The authors have no professional relationships with any company or manufacturer who would benefit from the current study results.

Data availability: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Please contact the authors for data requests.

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