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Maximal oxygen uptake and power of lower limbs during a competitive season in triathletes

O. Galy[1], J. Manetta[2], O. Coste[3], L. Maimoun[3], K. Chamary[4], O. Hue[1]

[1]Laboratoire ACTE, Unité de Formation et de Recherche des Sciences Techniques des Activités Physiques et Sportives, Antilles-Guyane, Campus de Fouillole, 97159 Pointe à Pitre Cedex, France, [2]Service de Physiologie Clinique, CERAMM, Center Hospitalier Universitaire, 34295 Montpellier Cedex 5, France, [3]Laboratoire de Physiologie des Interactions, Service Central de Physiologie Clinique, Unité d'Exploration Respiratoire, Center Hospitalier Universitaire Arnaud de Villeneuve, 34295 Montpellier Cedex 5, France, [4]Centre National de la Médecine du Sport, Ave Mohamed Ali Akid, 1004 El Menzah, Tunisia
Corresponding author: Olivier Galy, UFR-STAPS Antilles-Guyane, 97159 Pointe à Pitre, France

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Background: **In order to study the effect of a competitive triathlon season on maximal oxygen uptake (VO_{2max}), aerobic power (AeP) and anaerobic performance (AnP) of the lower limbs, eight triathletes performed exercise tests after: (1) a pre-competition period (Pre-COMP) (2) a competitive period (COMP), and (3) a low (volume and intensity) training period (Post-COMP). The tests were a vertical jump-and-reach test and an incremental exercise test on a cycle ergometer. Ventilatory data were collected every minute during the incremental test with an automated breath-by-breath system and the heart-rate was monitored using a telemetric system.** ***Results:*** **No changes in VO_{2max} were observed, whereas AeP decreased after Post-COMP compared to Pre-COMP and COMP and AnP decreased during COMP compared to Pre-COMP and Post-COMP. In addition, second ventilatory threshold (VT_2) and power output at first ventilatory threshold (VT1) and VT_2 decreased after Post-COMP.** ***Conclusion:*** **This study showed that six weeks of low volume and intensity of training is too long a period to preserve adaptations to training, although a stable maximal oxygen uptake throughout the triathlon season was observed. Moreover, the AnP decrease during COMP was probably in relation with the repetitive nature of the training mode and/or triathlon competitions.**

In endurance events, several factors have been demonstrated to be correlated with performance. These include maximal oxygen uptake (VO_{2max}), ventilatory thresholds, power (i.e., during cycling test) or velocity (i.e., during running test) developed at VO_{2max} and at ventilatory thresholds, running economy (RE) and maximal treadmill running performance (Conley & Krahenbuhl, 1980; Morgan, Martin, Krahenbuhl, 1989; Noakes, Myburgh, Schall 1990; Billat & Koralsztein, 1996; Paavolainen, Häkkinen, Hämäläinen, Nummela, Rusko, 1999). Explosive strength training is also important during aerobic activities, especially running (Paavolainen et al., 1999). Paavolainen et al. (1999) demonstrated that a specific nine week training program with simultaneous explosive strength and endurance training improved the five-kilometers run performance by improving RE and muscle power in well-trained athletes.

Other activities such as prolonged cycling and running or the triathlon decrease muscular strength after exercise (Hausswirth, Bigard, Guezennec, 1997; Lepers, Hausswirth, Mafiuletti, Brisswalter, Van Hoecke, 2000a,b). During a triathlon, the running segment is determinant to overall performance in today's races (Hue, Le Gallais, Chollet, Boussana, Préfaut, 1998; Millet, Millet, Hofmann, Candau, 2000). Changes in stride length and stride frequency are elicited, and these may be affected by changes in muscle properties (i.e., strength) (Hausswirth et al., 1997), as well as by an aptitude to maintain a high level of intensity (Hue, Le Gallais, Boussana, Chollet, Préfaut, 2000; Millet et al., 2000).

The anthropometric and physiological characteristics of triathletes have been well described, (Kohrt, Morgan, Bates, Skinner, 1987; Kreider, 1988; Roalstad, 1989) and both training volume (Laurenson, Fulcher, Korkia, 1993) and training intensity (Hue et al., 2000; Millet, Candau, Barbier, Busso, Rouillon, Chatard, 2002) influence the VO_{2max} and ventilatory thresholds in triathletes (Hue et al., 2000). However, within a competitive season, the variations in both aerobic (i.e., maximal oxygen uptake, ventilatory thresholds, power) and anaerobic performance remain unknown, even though these are widely considered to be determinant factors in performance (Paavolainen et al., 1999; Hue et al., 2000; Millet et al., 2000).

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The aim of the present study was thus to investigate aerobic and anaerobic performance during a competitive season in highly trained triathletes in relation with training schedule (i.e., volume and intensity).

Materials and methods

Subjects

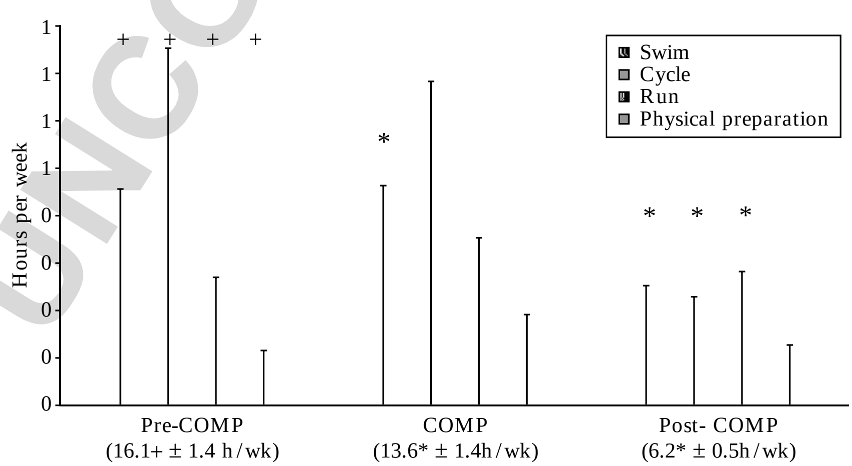
One female and seven male competitive triathletes participated in this study (age: 19.6 ± 0.2 years, body mass: 67.0 ± 1.9 kg, and height: 175.1 ± 1.8 cm). All were athletes of the Regional Center of Popular Education and Sports of Montpellier, France (Center Régional de l'Education Populaire et du Sport). Two of them were members of both the French Junior Team and the University Athletic Team. The others were nationally ranked and members of the Regional Junior Team and/or the University Athletic Team. All had been competing in the triathlon for 5.0 ± 0.3 years. All were non-smokers, had normal lung function, and gave no prior history of pulmonary or cardiovascular disease. Before the trials, the triathletes were familiarized with both the use of the cycle ergometer and the countermovement jump. All subjects gave informed written consent before participating in the protocol, which was in accordance with legal requirements and the Declaration of Helsinki, and was approved by the local ethics committee.

Protocols

All tests were conducted in an air-conditioned laboratory with a mean room temperature of 21.1 ± 0.1°C and a barometric pressure of 777.3 ± 4.8 mmHg. The tests were performed at the same time of day and on the same day of the week to minimize the effects of circadian rhythms and personal training. In addition, during the study period, they were also asked to refrain from training on experimental days. In the year preceding the study, the triathletes had agreed to follow a specific training schedule and to record their weekly training volume in swimming, cycling, running, and physical preparation, which is composed of specific exercises to improve abdominal muscle tone. They were trained daily by a professional coach who was specifically assigned to their group. The whole training year was divided into three periods: a pre-competition period (Pre-COMP) of 28 weeks with the first 16 weeks focused on high volume training in each triathlon component (i.e., swimming, cycling, and running) without triathlons and followed by 12 weeks of high volume training including progressive increase in intensity and specific multiblocks in cycling and running. The multiblock training consisted of repeated sessions of cycling and running consecutively in order to improve the specific phase of running after cycling in the triathlon (i.e., the cycle–run transition). A second competitive period (COMP) of 18 weeks emphasized high intensity training in each component and included approximately one triathlon every two weeks. A final post-competition period (Post-COMP) of six weeks was characterized by a large reduction in both training volume and intensity (Fig. 1), and triathletes were not allowed to compete. Table 1 presents a specific weekly training schedule for each period (Pre-COMP, COMP, Post-COMP) with specific times (X) dedicated to evaluating intensity or volume of training planned. Intensities were identified by three phases: (1) phase 1 or 'low intensity' < to the VT_1; (2) Phase 2 or 'moderate intensity' between VT_1 and VT_2; and (3) Phase 3 or 'high intensity' > VT_2; according to Skinner and McLellian (1980). A high training volume was a schedule over 15 h/week. High intensity was a schedule of only phase 2 and phase 3. Intensity was monitored by the triathletes with their own telemetry system (Polar Accurex plus, Polar Electro Oy, Kempele, Finland) and calculated from the results of VO_{2max}. In addition, differences observed between fig. 1 and Table 1 in the volume of training are due to the difference between the planned training schedule and the training actually performed by the triathletes during the entire study year.

Countermovement jump test

The first trial consisted of a jump-and-reach test performed using an ergojump (Jump-MD, Takeï, Japan) adjusted to each triathlete's height. The subjects were asked to perform a countermovement jump in which they began in a standing position, dropped into the semi-squat position, and immediately jumped as high as possible. The jump height was given automatically by the ergojump. Three tests were performed with five minutes of rest between them. The best jump was used for analysis (Vandewalle, Peres, Monod, 1987). All measurements were made with a precision of one centimeter. This method allowed us to evaluate their anaerobic performance (AnP). The power output during the jump-and-reach test was determined by entering the jump height and body weight variables into the equation of Sayers, Harackiewicz, Harman, Frykman, Rosenstein (1999): Maximal power (W) = 51.9 × CMJ height (cm) +48.9 × body mass (kg)—2007, where CMJ height is the height attained during the countermovement jump.



q1 *Fig. 1.*

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Table 1. Present a specific training schedule for each component (swim, cycle, run and physical preparation) during Pre-COMP, COMP and Post-COMP with specific (X) dedicated to evaluating intensity or volume of training planed. Intensity is expressed in Phase 1: low intensity $< VT_1$; Phase 2: moderate intensity between VT_1 and VT_2; high intensity $> VT_2$

A week of training	Swim	Cycle	Run	Physical preparation	Swim	Cycle	Run	Physical preparation	Swim	Cycle	Run	Physical preparation	Swim	Cycle	Run	Physical preparation
Day 1	1 h 30 min Phase 1		40 min Phase 2		1 h 30 min Phase 1		40 min Phase 3		1 h Phase 1		30 min Phase 2		1 h 30 min Phase 1			
Day 2	1 h 30 min Phase 1		45 min Phase 1	1 h Phase 1	1 h 30 min Phase 3		45 min Phase 1	1 h Phase 1	1 h Phase 3	2 h Phase 2		1 h Phase 1			35 min Phase 1	1 h Phase 1
Day 3		2 h 30 min Phase 1				2 h Phase 2				2 h Phase 3	45 min Phase 3		1 h Phase 1		35 min Phase 1	
Day 4	1 h 30 min Phase 2		50 min Phase 1		1 h 30 min Phase 3		50 min Phase 1		1 h 30 min Phase 3		50 min Phase 1			1 h Phase 1		
Day 5	1 h 30 min Phase 1		45 min Phase 2		1 h 30 min Phase 2		45 min Phase 2		1 h Phase 1	1 h 30 min Phase 2			1 h Phase 1			
Day 6		2 h Phase 1	30 min Phase 1			2 h 30 min multiblocks Phase 3			45 min or Phase 1	45 min or Phase 1	45 min Phase 1		45 min or Phase 1		35 min Phase 1	
Day 7		2 h Phase 1				3 h Phase 1				Triathlon Phase 3						
Triathlons		no				no				yes				no		
Volume of training	X X X	X X X	X X	X	X X	X	X X	X	X X	X X	X X	X	X	X	X X	X
Intensity of training	X	X	X	X	X X X	X X	X X	X	X X X	X X X	X X X	X	X	X	X X X	X
Duration Periods	 Pre-COMP	16 weeks				12 weeks COMP		 Post-COMP		18 weeks				6 weeks		

Maximal oxygen uptake test

After a recovery period of 45 min, in which anthropometric measures and an ECG were done, the triathletes performed an incremental test on an electronically braked cycle ergometer (Orion, S.T.E, Toulouse, France) to measure their maximal oxygen uptake and aerobic power (AeP). After a 3-min warm-up period at 60 W, power was increased by 30 W every minute until the subject reached volitional fatigue. Pedalling speed remained constant (72 r.p.m) throughout the test. All triathletes reached their maximal oxygen uptake with: (1) a leveling-off of VO_2 despite increasing load (2) respiratory exchange ratio (RER) greater than 1.10 (3) attainment of age-predicted maximal heart rate (HR) $\pm$ 5% (210–(0.65 age)), and (4) the inability of the subject to maintain pedalling frequency despite maximum effort and verbal encouragement.

Gas exchange measurements

The measuring instruments were calibrated before each test and ventilatory data were computed every minute using an automatic gas analyzer (CPX analyzer, Medical Graphics Corporation, Saint-Paul, MN): minute ventilation (V_E), oxygen uptake (VO_2), carbon dioxide production ($V\,CO_2$), respiratory exchange ratio (RER), respiratory equivalents for O_2 (V_E/VO_2) and CO_2 ($V_E/V\,CO_2$), respiratory rate (RR), and tidal volume (VT). Heart rate (HR) was measured using a telemetry system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). The two ventilatory thresholds (VT_1 and VT_2) were determined visually by two investigators, using a double-blind procedure. Both were defined from the time course curves of V_E and the ventilatory equivalents of O_2 $_{\text{and}}$ CO_2. The first ventilatory threshold, VT_1, was determined by a non-linear increase in $V_{E\ \text{and}}$ V_E/VO_2, without any increase in $V_E/V\,CO_2$ (Wasserman, Whipp, Casaburi, 1986). The second ventilatory threshold, VT_2, was identified by the second non-linear increase in V_E and V_E/VO_2 accompanied by a concomitant non-linear increase in $V_E/V\,CO_2$ (Ahmaidi, Hardy, Varray, Collomp, Mercier, Préfaut, 1993). Thresholds were expressed in terms of percentage of VO_2.

Statistical analysis

The results were expressed as means $\pm$ SEM. After verification of a normal distribution (Gaussian graphical distribution), the physical and maximal data, hours of training, AeP, AnP and cardioventilatory data (VO_2, V HR, VT_1, and VT_2) recorded throughout the incremental test were compared using a one-way analysis of variance (ANOVA) with repeated measures. When significant results were obtained with ANOVA, posthoc comparisons were made using Scheffe's posthoc test. Pearson product moment correlations were used to compare relationships between variables. Statistical analysis was performed using a computerized statistical software package (SYSTAT). Statistical significance was accepted at the $P < 0.05$ level.

Results

Training

The kinetics of the total training hours showed significant differences between periods ($P < 0.001$). Swim, cycle, run and physical preparation training were significantly lower in Post-COMP as compared with Pre-COMP ($P < 10^{-4}$, fig. 1). Swim training was significantly higher in Pre-COMP compared with COMP ($P < 0.03$, fig. 1). Swim, cycle, and run training were significantly higher in COMP compared with Post-COMP ($P < 10^{-2}$, $P < 10^{-4}$, $P < 10^{-4}$, respectively, fig. 1).

Aerobic power and cardioventilatory responses to incremental exercise

At VT_1 significantly different power values were observed in the three periods ($P < 0.02$; Table 2). In addition, as shown in Table 2, a significantly lower power was observed in Post-COMP when compared with Pre-COMP ($P < 0.05$) and COMP ($P < 10^{-2}$).

At VT_2 significantly different O_2 consumption, heart rate and power values were observed in the three periods ($P < 10^{-4}$, $P < 10^{-4}$ and $P < 10^{-4}$, respectively; Table 2). In addition, significantly lower O_2 consumption, HR and power at VT_2 were observed in Post-COMP when compared with both Pre-COMP ($P < 10^{-3}$, $P < 10^{-2}$ and $P < 10^{-4}$; Table 2) and COMP ($P < 10^{-3}$, $P < 10^{-2}$ and $P < 10^{-4}$; Table 2).

At maximal exercise significantly different maximal power values were observed in the three periods ($P < 10^{-3}$; fig. 2). In addition, as shown in Table 2, a significantly lower AeP was observed in Post-COMP compared with Pre-COMP ($P < 10^{-3}$) and COMP ($P < 0.003$).

Maximal performance obtained with CMJ

Figure 2 shows a significant difference among the three periods ($P < 0.008$). Moreover, a significant decrease in AnP was observed between Pre-COMP and COMP ($P < 0.03$), and a significant increase was noted between COMP and Post-COMP ($P < 0.02$).

Correlations

Figure 3 shows a significant inverse correlation between total training hours (cycle and run) and AnP ($r = -0.832$; $P < 0.01$; fig. 3) at Post-COMP. Moreover, at Post-COMP we noted a significant inverse correlation between running training hours and AnP ($r = -0.810$; $P < 0.01$) and a significant inverse correlation between cycling training hours and AnP ($r = -0.771$; $P < 0.02$).

Discussion and conclusions

The main findings of the present study were (1) the stability of maximal O_2 uptake throughout the entire triathlon training season independent of both training volume and training intensity, and (2) the decrease in anaerobic performance at the end of the competitive period. Furthermore, the VT_2 as well as the power output at VT_1 and VT_2, and AeP were significantly decreased after the postcompetitive period.

From a methodological point of view, we chose to assess VO_{2max} on a cycle ergometer based on the recent

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Table 2. Cardioventilatory and power parameters measured at rest, VT_1, VT_2, and maximal exercise during Pre-COMP,COMP and Post-COMP. * Significantly different from Post-COMP, $P < 0.05$. Values are means $\pm$ SEM

	VO_2 ($l.min^{-1}$)		VO_2 ($ml.min.kg^{-1}$)			
	Pre-COMP	COMP	Post-COMP	Pre-COMP	COMP	Post-COMP
Rest	0.5	0.4	0.4	8.7	7.0	6.5
0.0	0.0	0.0	0.5	0.9	0.5	
VT_1	2.7	2.7	2.5	41.3	40.6	37.3
0.1	0.1	0.2	2.6	2.2	3.6	
%	74.0	73.8	75.6	70.4	65.5	59.4
0.2	0.2	0.2	5.0	1.9	4.0	
VT_2	3.69*	3.67*	3.3	55.8*	55.4*	49.0
0.21	0.2	0.2	2.8	3.3	4.1	
%	88.9*	88.6*	79.0	90.4*	89.0*	78.3
0.2	0.2	0.2	1.9	1.5	4.2	
Max	4.15	4.14	4.2	62.7	62.0	62.1
	0.2	0.19	0.2	2.5	3.0	3.3
	HR ($beats.min^{-1}$)			Power (W)		
	Pre-COMP	COMP	Post-COMP	Pre-COMP	COMP	Post-COMP
Rest	67.0	65.8	69.5			
4.2	4.7	3.4				
VT_1	141.3	144.3	138.3	251.2*	247.5*	198.7
4.0	2.9	3.7	21.1	17.7	17.8	
%	79.2	79.1	75.7	64.2*	64.5*	54.6
2.0	1.3	2.7	3.7	3.3	3.9	
VT_2	169.6*	170.0*	160.3	371.2*	341.2*	281.2
2.2	3.1	4.1	17.8	22.6	22.6	
%	95.0*	93.1*	87.8	95.1*	88.7*	56.3
0.6	0.7	2.3	1.4	2.7	3.9	
Max	178.3	182.6	182.8	390.0*	382.5*	360.0
	1.8	2.7	2.8	17.9	16.7	16.0

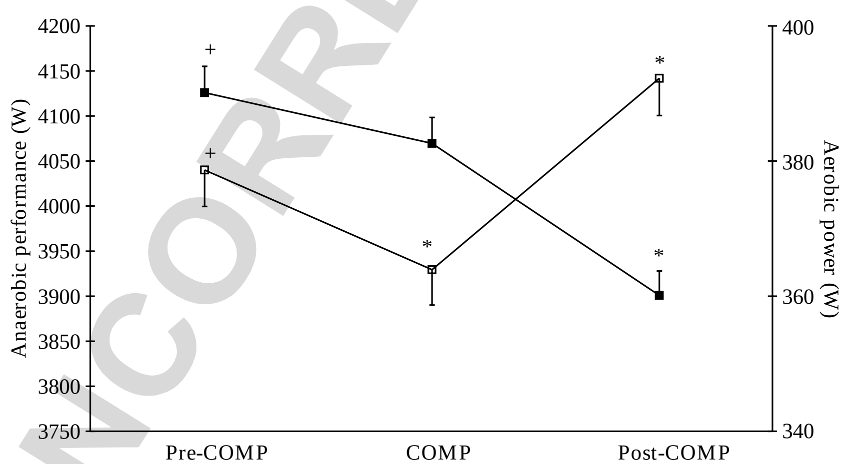

Fig. 2.

study of Hue et al. (2000), who showed similar VO_{2max} in young triathletes with treadmill and cycle ergometer testing. The authors demonstrated that these triathletes, without prior athletic specialization, probably developed similar VO_{2max} with both ergometers because of the cross-training effects of each discipline (i.e., cycling and running). Although most studies have explored anaerobic performance using the force-velocity (FV) test (Obert, Mandigout, Vinet, Courteix, 2001) or the Wingate test (Bar-Or 1987), some have investigated the effect of strength training on short-distance running performance using a five-jump test

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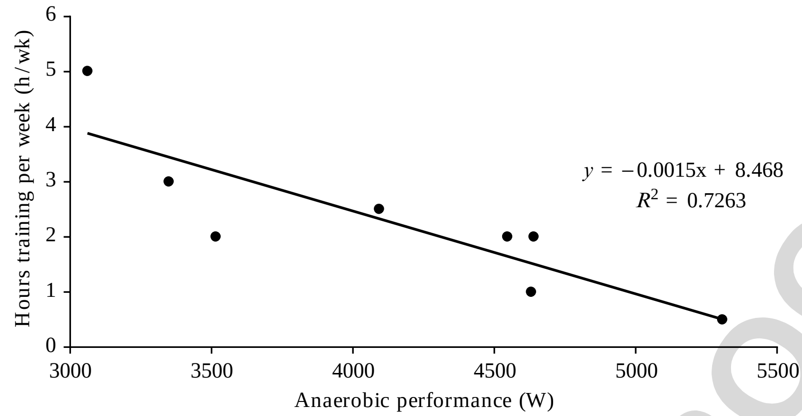

Fig. 3.

(Paavolainen et al., 1999) or after long distance running (2 h) using a CMJ (Lepers et al., 2000b). Moreover, the maximal CMJ is correlated with maximal anaerobic power as noted on a Monark ergometer (Vandewalle et al., 1987) and has been demonstrated to be the anaerobic performance best correlated to the different kinematic parameters of the run (Hoffman & Kang, 2002). Moreover, significant correlations have been demonstrated between peak torque on a 'Cybex' isokinetic ergometer and different jump tests (Bosco, Komi, Tihanyi, Fekete, Agor, 1983). Jones et al. (1985) noted that the energy required during fast-speed cycling was issued from instantly available ATP in muscle, the phosphocreatine system, and anaerobic glycolysis. Therefore, in spite of the brevity of each exercise bout, the anaerobic metabolism involved during both the FV and Wingate tests must be considered as both alactic and lactic anaerobic metabolism (Jones et al., 1985). In the present study, the jump-and-reach test was a maximal, extremely brief exercise that has been demonstrated to be an alactic anaerobic test (Davies & Young, 1984; Hertogh, Micallef, Mercier, 1992). The results of the present study, however, suggest some limitations. The CMJ is performed according to a variety of techniques (Van Zandwijk, Bobbert, Munneke, Pas, 2000), and it does not depend exclusively on maximal power, but also on the stretch reflex and neuromuscular coordination (Van Zandwijk et al., 2000). Both the magnitude and the rapidity of the countermovement contribute to vertical jump performance, and the variation in these factors contributes to error in maximal power prediction (Van Zandwijk et al., 2000). However, as each triathlete was compared to himself, we may assume that differences in jump technique would not have impaired CMJ measurements. Therefore, we cannot exclude the possibility that factors other than estimated power, such as the stretch reflex or neuromuscular co-ordination, were responsible for the difference in CMJ performance.

The present results show that during the entire competitive season (Pre-COMP, COMP, and Post-COMP), no differences in VO_{2max} were observed between periods. This may be explained by the continuous (but different) training pattern followed throughout the year and described in fig. 1 and Table 1. One to two weeks before the COMP tests, the triathletes participated in the French Triathlon Championship, which was considered as the major objective of the competitive season. The whole training schedule was thus organized around this key event. When such an event is placed at the end of the competitive season, highly trained triathletes often partially stop their intensive training and take a 'break' from competition, here called Post-COMP, for about six weeks. These six weeks appeared to be too short to reduce significantly the VO_{2max} and this finding reinforces the concept of cross-training effects suggested in triathletes (Hue et al., 2000; Millet et al., 2002). This is particularly so because of the significantly different cycling training volume (expressed in h/week) between the entire COMP and the Post-COMP periods (fig. 1). The transfers of training influences between different disciplines have been extensively studied and reviewed (Tanaka, 1994). The reduced training schedule during six weeks, with lower volume and intensity in each activity, resulted in a significantly lower AeP at VO_{2max} accompanied by a lower VT_2 at the end of Post-COMP, compared with Pre-COMP and COMP (Table 2). At the same intensity, two parameters significantly decreased: the power and HR responses. First, the power (at both VO_{2max} and VT_2) decrease might be explained by the large reduction in cycling training (from 5.3 ± 0.6 h/wk-1.5 ± 0.1 h/wk^{-1}) during Post-COMP. Bentley, Wilson, Davie and Zhou (1998) showed that AeP is a reliable variable to assess cycling performance in triathletes, confirming the reduced intensity of their training as shown by the lower VT_2 during the period. In spite of cross-effects, which have been shown between cycling and running (Hue et al., 2000; Millet et al., 2002), we could also suggest that reduced mitochondrial and capillary densities due to cycling training (Åstrand & Saltin, 1961; Saltin, 1977) were responsible for the

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diminished power during Post-COMP. Next, the significant decrease in HR at VT_2 seemed surprising. Usually if the power or VO_2 decreases at VT_1 or VT_2, the heart rate remains at the same level, signifying that the athlete can do less work at the same heart rate during a sub-maximal exercise. But in the present study both AeP and HR decreased, which means that the athletes could do the same work at the same HR. This could also be explained by their sub-maximal endurance capacity, which did not change between periods (Coyle & Martin, 1985). After Post-COMP, an increased reliance on carbohydrate metabolism during exercise probably resulted from a reduced insulin sensitivity and GLUT-4 transporter protein content, coupled with a lowered muscle lipoprotein lipase activity for a lower percentage of $V\,VO_{2max}$ and consequently accompanied by lower HR values (Mujika & Padilla, 2001). Lucia, Hyos, Peres, Chicharro (2000), in a similar longitudinal study in elite cyclists, observed no changes in either maximal O_2 uptake or physiological markers of performance including VT_1, VT_2 and lactate threshold between three different periods of training corresponding to a pre-competition period, a competition period and an active 'rest' period of two to three weeks. Although no changes in maximal O_2 uptake were observed throughout the whole triathlon competitive season, we assume that six weeks of low training was too long for highly trained triathletes to preserve their aerobic adaptations to training. The specific exercise (i.e., cycling) and/or the duration of the 'break' period was probably responsible for reduced muscular and cardiovascular adaptations at sub-maximal exercise, whereas only reduced muscular adaptations at maximal exercise were observed.

The results of the present study concerning anaerobic performance are quite surprising. At nearly the end of the COMP period, one to two weeks after the French Triathlon Championship, we observed a greatly diminished AnP, which may have limited running performance, as already demonstrated in athletes (Noakes 1988; Paavolainen et al., 1999). Avela, Kyrolainen, Komi, Rama (1999) demonstrated that six days after a marathon the impact time was both longer and lower in stretch-shortening cycle exercise compared to similar pre-marathon tests. Because the tests were conducted one to two weeks after the race, we cannot rule out that the race affected the CMJ results. However, the running distance of a marathon is approximately four times the triathlon running distance and even if it impacted the CMJ results, this would not totally explain the present data. One explanation could be the volume and intensity of training. The triathletes of the present study had high training volume and the effects of prolonged exercise such as running and cycling has been demonstrated to decrease muscular strength (Nicol, Komi, Marconnet, 1991; Lepers et al., 2000a,b). One could assume that when we compared both Pre-COMP and COMP to Post-COMP, the daily multi-training would have influenced muscle strength to decrease anaerobic performance as measured by the CMJ. However, because the training volume was higher during Pre-COMP than during COMP, this reasoning cannot be used. During COMP, only swimming volume was significantly reduced, whereas the intensity was substantially increased in each event (Table 1). As both prolonged (Nicol et al., 1991) and short-term intensive exercises (Nummela, Rusko, Mero 1994) induce a decrease in force-generating capacity, one could assume that the combination of high volume and high intensity significantly reduced anaerobic performance during COMP. At Post-COMP, after six weeks of low training, an inverse correlation was found between total training hours (cycle and run) and AnP ($r = -0.832$; $P < 0.01$, fig. 3) and, in addition, significant inverse relations were found between running training hours and AnP ($r = -0.810$; $P < 0.01$) and between cycling training hours and AnP ($r = -0.771$; $P < 0.02$), while no relations were found during the other periods. All these correlations suggest a deleterious effect of both high volume and high intensity on AnP. Another explanation could be the repeated competitions during the 18 weeks of the competitive period (with 10 ± 1.3 triathlons performed). These repeated competitions may have affected the neuromuscular system, which has already been demonstrated in marathon runners (Avela et al., 1999) and is perhaps here indicated by a significant reduction in anaerobic performance. This observation needs to be more fully explored, but we can raise the question of wasted benefits of training programs, mainly during the specific period of competition in which triathletes must turn in their best performances.

Perspectives

The findings of the present study showed no change in maximal O_2 uptake throughout the season, but AnP was decreased after the COMP period. Despite the primary importance of AeP and maximal O_2 uptake during endurance activities, anaerobic performance can improve overall performance during running in highly trained athletes (Noakes, 1988; Paavolainen et al., 1999). Thus, it might be interesting to more fully explore (1) the role of the anaerobic metabolism in triathletes and specifically in terms of their training, and (2) the value of specific explosive strength training simultaneously with endurance training in triathletes to evaluate its benefits.

Conclusions

In summary, this study showed stable maximal O_2 uptake throughout an entire triathlon season that was

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independent of training volume and intensity, while AeP, VT_2 and power output at VT_1 and VT_2 decreased after the Post-COMP period. This suggests that six weeks of low training seems to be too long for highly trained triathletes to preserve their physiological adaptations to training. In addition, AnP decreases after the competitive period of the season, suggesting that specific explosive strength training simultaneously with endurance training should be tested in triathletes to evaluate the benefits of such a method on running performance in the triathlon.

Key words: VO_{2max}; ventilatory thresholds; maximal aerobic power; parameters of performance; training; triathlon.

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