Zeitschrift IJSM sm176 **FO**
DOI 10.1055/s-2004-817923
FO
Satzbetrieb Ziegler + Müller
Verlag Thieme/Hentze
Datum 15.04.2004

S. Palazzetti[1]
I. Margaritis[1]
C. Y. Guezennec[2]

Swimming and Cycling Overloaded Training in Triathlon has no Effect on Running Kinematics and Economy

Abstract

The aim of the study was to verify whether an overloaded training (OT) in triathlon deteriorates running kinematics (RK) and running economy (RE). Thirteen well-trained male long-distance triathletes (age: 28.1 ± 4.3 yrs; $\dot{V}O_{2max}$: 65.0 ± 3.1 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) were divided into two groups: completed an individualized OT program (OG; n = 7) or maintained a normal level of training (NT) (CG; n = 6) for a duration of 3 weeks. Every week, each triathlete completed a standardized questionnaire to quantify the influence of training loads on mood state. To reach OT, total training load ($h \cdot 3\,wk^{-1}$) was increased by 24%; swimming and cycling total volumes were increased by 46 and 57%, respectively, but the distance run was not modified in order to limit the risk of injuries. RK and RE were determined on treadmill test at $12\,km \cdot h^{-1}$ before and after the 3 weeks. The 3-week swimming and cycling OT in triathlon was sufficiently stressful to alter mood state but not to deteriorate the running kinematics and economy parameters in our previously well-trained male long-distance triathletes.

Key words
Overloaded training · running kinematics · running economy · triathlon

Nomenclature of the Different Kinematic Data Averaged over 5 Running Cycles

Step length (cm)	distance from right heel contact to left heel contact
Support phase (s)	time in support phase
Non-support phase (s)	time in non-support phase
Trunk angle at footstrike (degrees)	angle of trunk with the vertical at footstrike
Trunk angle at toe-off (degrees)	angle of trunk with the vertical at toe-off
Trunk gradient (degrees)	mean difference of trunk angle at toe-off and trunk angle at footstrike
Hip vertical oscillation (cm)	vertical oscillation of hip during running cycles
Maximal hip height (cm)	maximal elevation of hip during running cycles
Minimal hip height (cm)	minimal elevation of hip during running cycles
Thigh at footstrike (degrees)	angle of thigh with the vertical at footstrike
Thigh at toe-off (degrees)	angle of thigh with the vertical at toe-off
Knee at footstrike (degrees)	angle made by thigh and leg at footstrike
Knee at toe-off (degrees)	angle made by thigh and leg at toe-off

Affiliation
[1] Laboratoire de Physiologie des Adaptations, Performance Motrice et Santé. Faculté des Sciences du Sport, Université de Nice-Sophia-Antipolis, France
[2] Département de Physiologie, IMASSA-CERMA, Bretigny-sur-Orge, France

Correspondence
S. Palazzetti · Laboratoire de Physiologie des Adaptations, Performance Motrice et Santé · Faculté des Sciences du Sport · Université de Nice-Sophia-Antipolis · 261 Route de Grenoble, BP 3259 · 06205 Nice Cedex 3 · France · Phone: ■ · Fax: + 33 4 93 83 06 30 · E-mail: palazzet@unice.fr

Accepted after revision: January 12, 2004

Bibliography
Int J Sports Med 2004; 25: 1 – 7 © Georg Thieme Verlag KG · Stuttgart · New York · DOI 10.1055/s-2004-817923 · ISSN 0172-4622

Zeitschrift IJSM sm176 **FO** Satzbetrieb Ziegler + Müller
DOI 10.1055/s-2004-817923 Verlag Thieme/Hentze
FO Datum 15.04.2004

Maximal knee angle (degrees)	maximal angle made by thigh and leg during flexion in non-support phase
Ankle vertical oscillation (cm)	vertical oscillation of ankle (right exterior malleolis) during running cycle
Ankle cyclograph (cm^2)	cyclograph area of ankle (right exterior malleolis) during running cycle

Introduction

Triathlon is a multievent sport that involves three events (swimming, cycling, running) done sequentially [27]. At the end of a triathlon, central and/or peripheral fatigue – induced by long duration exercise – causes a decrease in running economy (RE) [16, 18,19]. RE, defined as the oxygen consumption at a given submaximal running velocity, is a determinant of distance running performance [7,38]. Dengel et al. [9] showed that RE is significantly related to running performance time during a triathlon race.

Several physiological and biomechanical factors account for the variations in RE [17,29]. Increased RE is associated with muscle glycogen depletion, altered substrate utilization, changes in stride length and frequency, and changes in muscle activation [1,6,8,12,38]. For triathlon, decreased RE is associated with running kinematic (RK) changes in comparison with a control run done at the same speed [18].

Progressive overload is the foundation of all successful training. According to the general adaptation syndrome, stress causes a temporary decrease in function followed by an adaptation that improves function [26]. In the training response, overload is the stress that causes fatigue (temporary decrease in exercise ability), and improved performance (following recovery from fatigue) is the adaptation [14]. Sudden increment in training load (volume and/or intensity) and/or decreased rest periods may lead to physiological, biomechanical, and psychological perturbations [32].

Long distance triathlon training is characterized by high volume training loads that can induce an overtraining state [33]. Physiological or psychological signs of disturbances associated to a short-term decrement in performance capacity can be induced by overloaded training (OT) and nontraining stress [23,27]. The aim of the study was to verify whether an OT in triathlon affects RK and RE such as during long exercise bouts in case of acute fatigue [18].

Materials and Methods

Subjects

Thirteen well-trained male triathletes volunteered to participate in this study. They were divided into two groups: completed an individualized overloaded training (OT) program (OG; n = 7; age 28.6 ± 5.6 yrs; height 175.1 ± 8.5 cm; body mass 67.4 ± 7.4 kg; body fat 11.2 ± 4.2 %; $\dot{V}O_{2max}$ 65.8 ± 3.4 $ml \cdot min^{-1} \cdot kg^{-1}$) or maintained a normal level of training (NT) (CG; n = 6; age 27.5 ± 2.3 yrs; height 179.0 ± 12.4 cm; body mass 74.1 ± 7.8 kg; body fat 11.8 ± 1.4 %; $\dot{V}O_{2max}$ 63.9 ± 2.6 $ml \cdot min^{-1} \cdot kg^{-1}$) for a duration of 3 weeks. Triathletes were long-distance competitors who manage social, occupational, family, and sporting activities. Experimental procedures were approved by the Committee for the Protection of Persons in Biomedical Research (No. 97 001), and all triathletes gave written informed consent after the purpose, possible risks, and stress associated with the study were explained.

Experimental design

Each triathlete completed four assessment sessions in a 24-day period (Fig. **1**). On the days of assessments, all triathletes refrained from any training session. They were instructed to refrain from making any drastic changes in diet throughout the 3-week study and to consume exactly the same diet for 2 days before each assessment. Seven days after medical evaluation and maximal oxygen uptake ($\dot{V}O_{2max}$) determination, triathletes were in-

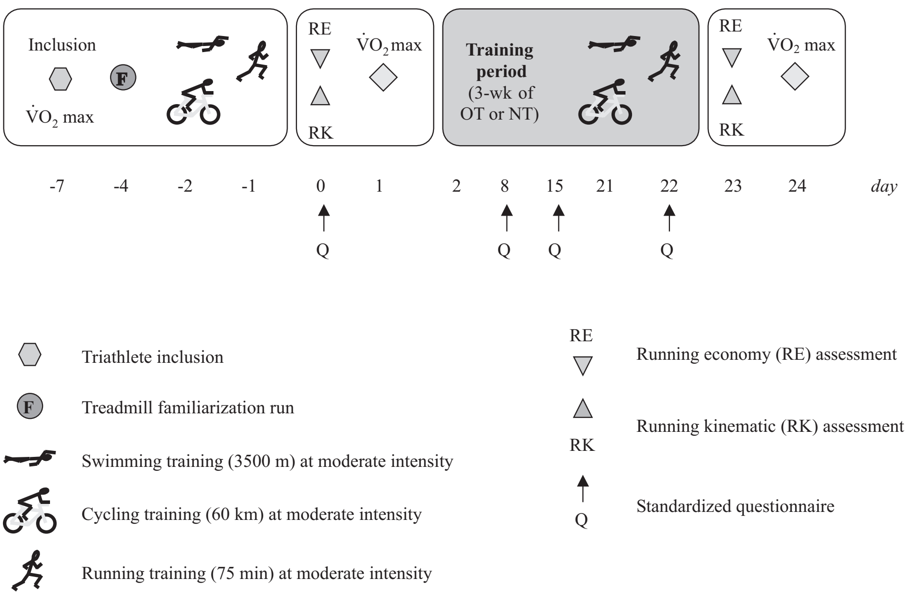

Fig. **1** Summary of experimental design.

Zeitschrift IJSM sm176 **FO** Satzbetrieb Ziegler + Müller
DOI 10.1055/s-2004-817923 Verlag Thieme/Hentze
FO Datum 15.04.2004

cluded in the experimental design. In the first assessment, running economy (RE) and running kinematics (RK) were determined on motorized treadmill (2500 ST, GYMROL, Andrézieux-Bouthéon, France). During the second assessment, maximal oxygen uptake ($\dot{V}O_{2max}$) was measured again. The third and the fourth assessment sessions, identical to previous, were repeated after 3 weeks of individualized training (OT or NT). To attenuate the influence of circadian variation and footwear on RE and gait mechanics [28], triathletes performed all testing at the same time of day and with the same shoes. Four days before the first assessment, triathletes did three 10-min motorized treadmill familiarization runs at 10, 11, and 12 $km \cdot h^{-1}$ (2% slope). Cavanagh and Williams [6] showed a 30-min treadmill familiarization run is sufficient to establish a consistent treadmill running pattern. Two days after the runs, each triathlete trained in swimming (3500 m) and cycling (60 km) at moderate intensity. The following day, they performed a 75-min run at 12 $km \cdot h^{-1}$. At the end of training program (days 21 and 22), they performed the same training sessions (Fig. **1**).

Sessions 1 and 3: running economy (RE) assessment and motion analysis

Throughout the submaximal assessments, the treadmill speed was controlled continuously by a photoelectric cell. RE was assessed before RK. To calculate RE, the oxygen uptake ($\dot{V}O_2$) was measured on a breath-by-breath basis using an automatic spiroergometric system (Vmax 29, Sensor Medics, Rungis, France). After a warm-up at 10 $km \cdot h^{-1}$ (2% slope) for 5 min, triathletes ran at 12 $km \cdot h^{-1}$ (2% slope) – corresponding to 65.8 ± 5% of $\dot{V}O_{2max}$ – for 10 min. The 12 $km \cdot h^{-1}$ run speed imposed in this study is commonly used by long-distance triathletes during their long-distance triathlon competitions on 30 to 42.2 km run. The 2% slope was used to compensate the absence of movement resistance in laboratory conditions. Data were collected and averaged during the fifth to tenth minute of running at steady state. RE is calculated – against nonaerodynamic forces – by the formula of di Prampero [11]:

$$RE = \frac{(\dot{V}O_2 - \dot{V}O_{2rest})}{velocity} \times 60$$

RE is expressed in ml $O_2 \cdot kg^{-1} \cdot km^{-1}$, $\dot{V}O_2$ in ml $O_2 \cdot min^{-1} \cdot kg^{-1}$, and velocity in $km \cdot h^{-1}$. $\dot{V}O_2$ rest was recorded during one minute before the warm-up and the last 30-s values were used. Heart rate (HR) was monitored continuously and recorded using an electrocardiograph monitor (HELLIGE, SMS 182, Freibourg in Breisgau, Germany).

Motion analysis was performed using a computer-aided video motion analysis system (KINEMETRIX, Medical Research Ltd, Leeds, United Kingdom) with three infrared cameras operating at a nominal rate of 50 $frames \cdot s^{-1}$. All of the experiments were done using the same experimental set-up: Three CCD-cameras were lined up 1.5 m apart at an exact distance of 4.75 m, 4.5 m, and 4.75 m for cameras 1, 2, and 3, respectively. The cameras were used to record a sagittal view of the running motions. The measurement space was calibrated before each assessment.

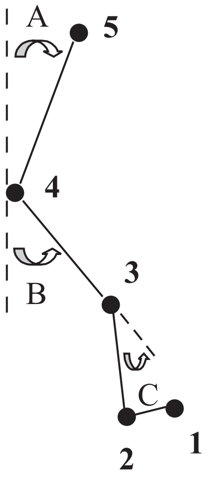

Fig. **2** Conventional measurements of the angles and specific points used to calculate the RK data. A = angle trunk/vertical; B = angle thigh/vertical; C = angle thigh lower leg (knee); 1 = fifth metatarsal; 2 = lateral malleolis; 3 = lateral condyle femoral; 4 = iliac crest; 5 = acromion process.

To record the articular displacement, the triathletes were in bathing trunks, bringing to the fore the anatomical markers. The anatomical points were determined with the subjects in upright position by placing reflective markers on the right side of the body over the fifth metatarsal, lateral malleolis, lateral condyle femoral, iliac crest, and acromion process (Fig. **2**).

RK data were recorded during the first and the fourth minute of the treadmill run at 12 $km \cdot h^{-1}$ (2% slope) immediately after RE assessment. Five out of seven running cycles of data from each testing session were selected and the means and standard deviations for each parameter studied were computed for each triathlete. The parameters studied are reported in the Nomenclature. The means and standard deviations of each point of the running cycle were determined by averaging the mean kinematic data. Note that RE was not calculated during RK data recording.

Sessions 2 and 4: Maximal oxygen uptake ($\dot{V}O_{2max}$) assessment

Triathletes performed a continuous, incremental running test on a motorized treadmill during visit inclusion, and before and after the training program (Fig. **1**). The test began with a warm-up at 10 $km \cdot h^{-1}$ (2% slope) for 5 min; running speed was then increased by 2 $km \cdot h^{-1}$ every 2 min up to 14 $km \cdot h^{-1}$ and by 1 $km \cdot h^{-1}$ until exhaustion. Ventilatory and gas exchange responses were measured on a breath-by-breath basis using an automatic spiroergometric system (Vmax 29, Sensor Medics, Rungis, France). Throughout the test, HR was monitored continuously and recorded using an electrocardiograph monitor (HELLIGE, SMS 182, Freibourg in Breisgau, Germany). The criteria used for determining $\dot{V}O_{2max}$ were a plateau in $\dot{V}O_2$ despite an increase in load or running speed, a respiratory exchange ratio (RER) above 1.1, and an HR over 90% of the predicted maximal HR [2].

Training program

Triathletes underwent 3 weeks of NT (swimming: 24.3 ± 6.3 $km \cdot 3\,wk^{-1}$, cycling: 523.8 ± 206.7 $km \cdot 3\,wk^{-1}$, and running: 109.6 ± 35.9 $km \cdot 3\,wk^{-1}$) before completing an individualized OT program in triathlon or maintaining an NT during 3 weeks (January – February 1997) (Table **1**). OT was quantified based on training loads achieved during the month before the study. The significant correlations found between the total volume, corresponding to the sum of the training durations in swimming, cycling, and running, and $\dot{V}O_{2max}$ (r = 0.63) served as validation of the

Zeitschrift IJSM sm176 **FO**
DOI 10.1055/s-2004-817923
FO
Satzbetrieb Ziegler + Müller
Verlag Thieme/Hentze
Datum 15.04.2004

Table **1** Quantification of training loads in swimming, cycling, and running in NT and OT for overloaded (OG, n = 7) and control (CG, n = 6) triathletes (means ± SD) (* p < 0.05)

		NT	*OT*	*ANOVA (Group × Training)*
Swimming ($km \cdot 3\,wk^{-1}$)	OG	23.6 ± 7.4	31.6 ± 4.1*	p < 0.05
	CG	25.3 ± 5.2	24.7 ± 5.9	(F = 4.6)
Cycling ($km \cdot 3\,wk^{-1}$)	OG	589.3 ± 175.5	888.7 ± 212.8*	p < 0.001
	CG	447.5 ± 229.3	401.2 ± 242.2	(F = 32.5)
Running ($km \cdot 3\,wk^{-1}$)	OG	122.1 ± 35.1	116.0 ± 29.3	NS
	CG	95.0 ± 33.8	100.3 ± 63.0	
Total training load ($h \cdot 3\,wk^{-1}$)	OG	39.1 ± 6.1	47.9 ± 7.7*	p < 0.05
	CG	32.3 ± 5.3	32.4 ± 8.0	(F = 8.5)

Table **2** Distress clinical symptoms for the overloaded (OG; n = 7) triathletes in response to 3-week OT period (*p < 0.05)

Clinical symptoms	*F value*
Decrease in training pleasure	4.82*
Sleep disturbances	3.43*
Subjective fatigue	3.82*
Vulnerability to respiratory tract infections	3.24*
Memory disturbances	3.82*
Decrease in professional efficiency	3.80*
Irritability	3.02
Digestive disturbances	0.83
Muscle soreness	1.91
Loss of training desire	2.56

training load the triathletes reported (n = 13). During OT, total training load ($h \cdot 3\,wk^{-1}$) was increased by 24%; swimming and cycling total volumes were increased by 46 and 57%, respectively, but the distance run was not modified in order to limit the risk of injuries during these 3 weeks (Table **1**). To reach OT, swimming intensity was also increased.

During the 3-week training period, triathletes kept a daily training log of swimming, cycling, and running volumes, and subjective ratings of training intensity (modified Borg's scale) [4] rated on a fifteen-point scale to 1) analyze characteristics of training sessions completed in comparison with those planned and 2) assure that training intensity imposed was maintained in the course of this investigation. In conclusion, after training log analysis, it appeared that the planned individualized training programs were respected by all triathletes in spite of fatigue feeling.

Psychological assessment

Every week, each triathlete completed a standardized questionnaire designed by the "Société Française de Médecine du Sport" to quantify the influence of training loads on mood state (Fig. **1**). The questionnaire we used has been devised to report symptoms associated with overreaching or overtraining syndrome [25]. It was composed of 52 questions which could be answered *yes* or *no*. A triathlete was considered overloaded when affirmative responses to the questionnaire increased relative to the reference period.

Statistical analysis

All data are expressed as means and standard deviations (SD). Effect of the training period on kinematic and physiological data was determined by analyzing the differences between the before- and after-training group means in a two-way analysis of variance (ANOVA) mixed design (two levels of time and two levels of group). When significant changes were observed in ANOVA, Fisher's PLSD *post-hoc* test was applied to locate the source of significant differences. Relationships between selected variables were evidenced by Pearson's correlation analysis. In the case of the *yes-no* questions, a proportional analysis was performed [35]. The means, standard deviations, and F-ratios for the psychometric variables are presented in Table **2**. Statistical significance level was set at p < 0.05.

Results

Psychological data

The proportional analysis for the psychometric variables shows that the psycho-behavioral state for the overloaded triathletes (OG; n = 7) was significantly altered by 3 weeks of OT (Table **2**). On the other hand, no significant change was observed for the other group (CG; n = 6) after 3 weeks of NT.

Kinematic data

Body segments, joint angles: The mean segmental angular position values of the trunk and the thigh, the knee angles and the kinematic parameters calculated for both hip and ankle were not significantly changed in response to training period (OT or NT) for the overloaded (OG; n = 7) and control (CG; n = 6) triathletes, respectively (Table **3**).

Stride length: No significant difference was observed for the stride length values in response to training period (OT or NT) for the overloaded (OG; n = 7) (100.1 ± 6.1 vs. 98.7 ± 6.5 cm) and control (CG; n = 6) (102.3 ± 10.5 vs. 101.5 ± 10.8 cm) triathletes.

Table **3** Segmental angular position of trunk and thigh, joint angle values of the knee, oscillation vertical values of the hip and the ankle, the maximal and minimal hip height values, and the ankle cyclograph area (means ± SD) for the overloaded (OG; n = 7) and control (CG; n = 6) triathletes before and after training (OT and NT, respectively). There was no significant difference in response to training period

	Overloaded Group		*Control Group*	
	Before	*After*	*Before*	*After*
Trunk angle at footstrike (deg)	– 0.1 ± 3.5	0.2 ± 3.3	0.7 ± 3.6	0.5 ± 3.0
Trunk angle at toe-off (deg)	11.9 ± 2.6	13.0 ± 1.1	11.8 ± 4.1	12.7 ± 3.1
Trunk angle (deg)	12.0 ± 2.7	12.6 ± 3.1	11.1 ± 2.8	12.2 ± 0.9
Thigh at footstrike (deg)	27.4 ± 2.1	27.6 ± 2.0	26.7 ± 3.5	26.8 ± 4.2
Thigh at toe-off (deg)	– 16.9 ± 2.3	– 16.2 ± 1.8	– 18.1 ± 3.0	– 16.5 ± 3.0
Knee at footstrike (deg)	20.2 ± 2.7	22.2 ± 2.7	18.3 ± 6.4	20.7 ± 6.3
Knee at toe-off (deg)	25.2 ± 5.7	28.4 ± 5.6	23.4 ± 5.9	26.6 ± 6.5
Maximal knee angle (deg)	95.5 ± 15.4	96.1 ± 13.0	88.2 ± 4.9	90.7 ± 5.5
Hip vertical oscillation (cm)	8.8 ± 1.1	8.6 ± 0.7	8.3 ± 1.6	8.0 ± 1.6
Maximal hip height (cm)	12.6 ± 1.5	12.4 ± 1.7	12.6 ± 2.6	12.6 ± 2.2
Minimal hip height (cm)	3.8 ± 1.3	3.9 ± 1.8	4.2 ± 1.2	4.5 ± 0.9
Ankle vertical oscillation (cm)	37.8 ± 11.1	37.1 ± 9.3	33.7 ± 3.7	33.3 ± 4.1
Ankle cyclograph (cm^2)	1793.4 ± 699.2	1715.3 ± 591.7	1532.6 ± 201.6	1524.8 ± 163.5

Table **4** Physiological data (means ± SD) for the overloaded (OG; n = 7) and control (CG; n = 6) triathletes before and after training (OT and NT, respectively). There was no significant difference in response to training period ($\dot{V}O_{2max}$ = maximal oxygen uptake; RE = running economy at 12 km · h^{-1}; $\dot{V}O_2$ = oxygen uptake at 12 km · h^{-1})

	Overloaded Group		*Control Group*	
	Before	*After*	*Before*	*After*
Body mass (kg)	67.4 ± 7.4	66.7 ± 7.1	74.1 ± 7.8	74.0 ± 7.7
$\dot{V}O_{2max}$				
(ml O_2 · min^{-1} · kg^{-1})	65.8 ± 3.4	65.0 ± 5.3	63.9 ± 2.6	63.5 ± 3.1
(l O_2 · min^{-1})	4.403 ± 0.404	4.309 ± 0.395	4.735 ± 0.440	4.693 ± 0.414
RE (ml O_2 · kg^{-1} · km^{-1})	188.1 ± 10.6	195.3 ± 19.0	187.5 ± 14.4	185.6 ± 16.0
$\dot{V}O_2$				
(ml O_2 · min^{-1} · kg^{-1})	42.6 ± 2.1	44.0 ± 3.8	42.5 ± 2.9	42.1 ± 3.2
(l O_2 · min^{-1})	2.869 ± 0.322	2.941 ± 0.435	3.167 ± 0.543	3.133 ± 0.544

Physiological data

Physiological data for the overloaded (OG; n = 7) and control (CG; n = 6) triathletes are reported in Table **4**. There was no significant change in physiological variables in response to 3 weeks of OT or NT.

Relationship between kinematic data, physiological data, and training loads

No correlations were found between kinematic and physiological data. Physiological data were not correlated with training loads in swimming, cycling, and running.

Discussion

Although many studies have examined the effects of training on running mechanics and/or economy in untrained [3,24] and well-trained [5,37] subjects, to our knowledge, no simultaneous assessment has been made of mechanic and energetic variables in overloaded triathletes.

The 3-week OT in triathlon altered psychological mood (Table **2**) which indicates the total training load was clearly stressful. This OT response has been observed in swimming [30], cycling [21], and running [13]. Verde et al. [36] reported that traditional physiological indicators of overtraining were not helpful in assessing overtraining, and that the only measurement that gave a consistent response to heavy training was the psychological indicators. In some training-induced stressful conditions, psychological data agree with physiological data [30]. This argues in favor of the helpful role of psychological data in order to confirm the overwhelming effect of training, and monitor distress in endurance athletes.

Zeitschrift IJSM sm176 **FO** Satzbetrieb Ziegler + Müller
DOI 10.1055/s-2004-817923 Verlag Thieme/Hentze
FO Datum 15.04.2004

OT program was elaborated to overwhelm adaptive capacities. In this condition, homeostasis disturbances would be temporary associated with central fatigue. Inasmuch as we analyzed the variables with respect to running, the lack of specific overload on running, intended to limit the risk of injuries, restricts our interpretations to central cause and not peripheral.

In response to high training loads, and particularly in endurance activities, the immune system weakens and thus the vulnerability to respiratory tract infections increases [15], as observed in our study. On the other hand, the sleep and memory disturbances and lack of attention reported in response to 3 weeks of OT (Table **2**) suggest that our triathletes manifest central fatigue.

Classically, skeletal muscle damage appears in response to OT. It has been suggested that altered gait mechanics and higher aerobic demand of running during exercise would be due to the recruitment of additional motor units to maintain force generation, commonly evidenced by change in electromyographic activity [34], in spite of damages to skeletal fiber, which continue to use oxygen [10]. It thus appears that the individualized OT program proposed in our study was not of sufficient volume and/or intensity to alter basic motor unit recruitment patterns.

Our study also supports the notion that RE and related gait descriptors are not perturbed easily in previously well-trained triathletes. This stability of RE may have been due to the fact that the neuromuscular coordination on which running depends is so phylogenetically old that it cannot be easily altered, except in pathological conditions [31].

In this study, biomechanical assessments were limited to a single moderate speed of running ($12\ km \cdot h^{-1}$ corresponding to average of 65% of $\dot{V}O_{2max}$) that was close to the average training pace for the long-distance triathletes. It was postulated that the triathletes would finely tune their mechanical movement patterns at their training pace. However, it is feasible that changes in RE and running mechanics with training are speed-dependent. With this in mind, it would be beneficial to examine triathletes over a range of speeds before and after training programs.

Our results suggest that during an OT, running mechanics are resistant to change in previously well-trained triathletes. It remains to be determined whether general changes in mechanics can be observed over a much longer duration of OT. On the other hand, RK parameters in our study seem more sensitive to acute exercise-induced stress level [18] than to OT.

Other mechanical aspects of running technique, not measured here, could have changed. Kinematic measurements were made in the sagittal plane on the right side of the body only. It is plausible that kinematic changes could have occurred with OT in other planes.

In our study, the mechanics of the running gait may be discussed in terms of kinematics, the geometry of motion, and not in term of kinetics, which deal with forces producing motion [20]. In our overloaded triathletes, the lack of stride kinematic changes shows indirectly the lack of mechanical energy production changes. Only a dynamic analysis would confirm this hypothesis. Considering the practical applications of our kinematic findings, note that the lack of change in RK parameters in previously well-trained triathletes undergoing OT suggests they are not at a higher risk of musculoskeletal injuries. It is well established that changes in running pattern with chronic fatigue contribute to such injuries [22].

In summary, during the 3 weeks of OT, total training load in triathlon was progressively increased and sufficiently stressful to alter mood state but not to deteriorate the running kinematics and economy parameters in our previously well-trained long-distance triathletes. Several hypotheses may explain these results: a low magnitude of the break of the habitual training structure and training load, a shorter duration of OT period, a high level of training adaptation in initial conditions, intra-individual adaptations to fatigue, and the specificity of the parameters studied. These various factors have to be studied in a controlled manner to define precisely how they act in the effects of chronic fatigue on RK and RE. We conclude that the central and/or peripheral fatigue induced by short-term OT induces no alteration pattern in motor or in aerobic demand in previously well-trained male long-distance triathletes.

References

1 Armstrong RB, Marum P, Saubert CW, Seeherman HJ, Taylor RC. Muscle fiber activity as a function of speed and gait. J Appl Physiol 1977; 43: 672 – 677
2 Astrand I, Astrand PO, Hallbäck A, Kilbom A. Reduction in maximal oxygen uptake with age. J Appl Physiol 1973; 35: 649 – 654
3 Bailey SP, Messier SP. Variations in stride length and running economy in male novice runners subsequent to a seven-week training program. Int J Sports Med 1991; 12: 299 – 304
4 Borg GAV. Perceived exertion. Exerc Sport Sci Rev 1974; 2: 131 – 153
5 Brisswalter J, Legros P, Durey A. Variabilité du coût énergétique de la course à pied: Effets de la spécificité de la vitesse d'entraînement sur l'évolution des paramètres physiologiques et cinématiques de la course à pied. Science & Motricité 1995; 25: 3 – 11
6 Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. Med Sci Sports Exerc 1982; 14: 30 – 35
7 Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980; 12: 357 – 360
8 Costill DL, Fink WL, Getchell LH, Ivy JL, Witzmann FA. Lipid metabolism in skeletal muscle of endurance-trained males and females. J Appl Physiol 1979; 47: 787 – 791
9 Dengel DR, Flynn MG, Costill DL, Kirwan JP. Determinants of success during triathlon competition. Res Q Exerc Sport 1989; 60: 234 – 238
10 Dick R, Cavanagh P. An explanation of the upward drift in oxygen uptake during prolonged sub-maximal downhill running. Med Sci Sports Exerc 1987; 19: 310 – 317
11 di Prampero PE. The energy cost of human locomotion on land and in water. Int J Sports Med 1986; 7: 55 – 72
12 Elliot B, Ackland T. Biomechanical effects of fatigue on 10 000 meter running technique. Res Q Exerc Sport 1981; 52: 160 – 166
13 Flynn MG, Pizza FX, Boone Jr JB, Andres FF, Michaud TA, Rodriguez-Zayas JR. Indices of training stress during competitive running and swimming seasons. Int J Sports Med 1994; 15: 21 – 26
14 Fry RW, Morton AR, Keast D. Periodisation of training stress – A review. Can J Sport Sci 1992; 17: 234 – 240
15 Fry RW, Morton AR, Keast D. Overtraining in athletes: An update. Sports Med 1991; 12: 32 – 65
16 Guezennec CY, Vallier JM, Bigard AX, Durey A. Increase in energy cost at the end of a triathlon. Eur J Appl Physiol 1996; 73: 440 – 445
17 Hausswirth C, Lehenaff ■. Physiological demands of running during long distance runs and triathlons. Sports Med 2001; 31: 679 – 689

Zeitschrift IJSM sm176 **FO** Satzbetrieb Ziegler + Müller
DOI 10.1055/s-2004-817923 Verlag Thieme/Hentze
FO Datum 15.04.2004

[18] Hausswirth C, Bigard AX, Guezennec CY. Relationships between running mechanics and energy cost of running at the end of a triathlon and a marathon. Int J Sports Med 1997; 18: 330 – 339
[19] Hausswirth C, Bigard AX, Berthelot M, Thomaïdis M, Guezennec CY. Variability in energy cost of running at the end of a triathlon and a marathon. Int J Sports Med 1996; 17: 572 – 579
[20] James SL, Brubaker CE. Biomechanical and neuromuscular aspects of running. In: Wilmore JH (ed). Exercise and Sport Sciences Reviews. Vol. 1. New York: Academic Press, 1973: 189 – 216
[21] Jeukendrup AE, Hesselink MKC, Snyder AC, Kuipers H, Keizer HA. Physiological changes in male competitive cyclists after two weeks of intensified training. Int J Sports Med 1992; 13: 534 – 541
[22] Jones BH, Cowan DN, Knapik JJ. Exercise, training and injuries. Sports Med 1994; 18: 202 – 214
[23] Kuipers H, Keizer HA. Overtraining in elite athletes: Review and directions for the future. Sports Med 1988; 6: 79 – 92
[24] Lake MJ, Cavanagh PR. Six weeks of training does not change running mechanics or improve running economy. Med Sci Sports Exerc 1996; 28: 860 – 869
[25] Legros P, le groupe Surentraînement. Le surentraînement: diagnostic des manifestations psychocomportementales précoces. Science Sport 1993; 8: 71 – 74
[26] Margaritis I, Palazzetti S, Rousseau AS, Richard MJ, Favier A. Antioxidant supplementation and tapering improve exercise-induced antioxidant response. J Am Coll Nutr 2003; 22: 147 – 156
[27] Margaritis I. Facteurs limitants de la performance en triathlon. Can J Appl Physiol 1996; 21: 1 – 15
[28] Morgan DW, Martin PE, Krahenbuhl GS, Baldini FD. Variability in running economy and mechanics among trained male runners. Med Sci Sports Exerc 1991; 23: 378 – 383
[29] Morgan DW, Martin PE, Krahenbuhl GS. Factors affecting running economy. Sports Med 1989; 7: 310 – 330
[30] Morgan WP, Costill DL, Flynn MG, Raglin JS, O'Connor PJ. Mood disturbance following increased training in swimmers. Med Sci Sports Exerc 1988; 20: 408 – 414
[31] Olgiati R, Jacquest J, di Prampero PE. Energy cost of walking and exertional dyspnea in multiple sclerosis. Am Rev Respir Dis 1986; 134: 1005 – 1010
[32] Palazzetti S, Richard MJ, Favier A, Margaritis I. Overloaded training increases exercise-induced oxidative stress and damage. Can J Appl Physiol 2003; 28: 588 – 604
[33] Palazzetti S, Margaritis I. Does overtraining occur in triathletes? Biol Sport 2003; 20: 139 – 146
[34] Poole DC. Role of exercising muscle in slow component of $\dot{V}O_2$. Med Sci Sports Exerc 1994; 26: 1335 – 1340
[35] Siegel S. Nonparametric Statistics. New York: McGraw-Hill, 1956
[36] Verde T, Thomas S, Shephard RJ. Potential markers of heavy training in highly trained distance runners. Br J Sports Med 1992; 26: 167 – 175
[37] Williams KR. Mechanical and physiological adaptations to alterations in running stride length. Med Sci Sports Med 1991; 23: 6
[38] Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. J Appl Physiol 1987; 63: 1236 – 1245