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ABSTRACT

Purpose: This study investigated the effects of a combined endurance and strength training on the physiological and neuromuscular parameters during a 2-hour cycling test. **Methods:** Fourteen triathletes were assigned to an endurance-strength training group (ES) and an endurance-only training group (E). They performed 3 experimental trials before and after training: an incremental cycling test to exhaustion, a maximal concentric lower-limbs strength measurement and a 2-hour cycling exercise. Physiological parameters, free cycling chosen cadence (FCC) and the EMG of Vastus Lateralis (VL) and Rectus Femoris (RF) were analysed during the 2-hour cycling task. **Results:** The results showed that the maximum strength and the isometric maximal voluntary contraction (isoMVC) after training were significantly higher ($P<0.01$) and lower ($P<0.01$) than before training, respectively in ES and E groups. The physiological variables measured during the cycling tests and the progressive increase ($P<0.01$) in $EMGi_{(VL)}$ and $EMGi_{(RF)}$ throughout the 2-hour cycling test did not differ between the two groups before and after training, except for the variation of $EMGi_{(VL)}$ over the cycle time which was stabilized during the second hour of the 2-hour cycling test due to training in ES group. The decrease in FCC observed in pre-training ($P<0.01$) was also replaced by a steady FCC for the ES-group during the second hour of exercise. **Conclusion:** This study confirmed the decrease in the FCC with exercise duration and demonstrated that a specific combined endurance and strength training can prevent this decrease during a 2-hour constant cycling exercise.

Key words: Freely chosen cadence, concurrent training, fatigue, cycling, prolonged exercice

INTRODUCTION

The studies focusing on long distance cycling exercises have shown a discrepancy between the freely chosen cycling cadence (FCC) and the energetically optimal cadence (EOC), i.e. the cadence at which the energy expenditure represented by the oxygen uptake ($\dot{V}O_2$) is minimal (Brisswalter et al., 2000; Lepers et al., 2000). For exercise lasting more than 30 minutes in duration, several authors have observed significant variations in FCC (Argentin et al., 2006; Lepers et al., 2000; Vercruyssen et al., 2001). In this framework, Lepers et al. (2000) reported that during a 2-hour constant exercise at 65% of maximal aerobic power (MAP) within a group of well-trained triathletes, the decrease in the FCC was higher with the increase in the exercise duration. According to these authors, the inability of the subjects to maintain a constant cycling cadence could be related to the emergence of neuromuscular fatigue, resulting in a change of neural and contractile properties of the quadriceps muscle such as alterations of the M-wave and isometric muscular twitch (Lepers et al., 2000). Argentin et al. (2006) have also observed a significant decrease in FCC (87 to 68 rpm) over two hours of cycling at 65% MAP. This pedalling cadence decrease is associated with a significant drop in maximal voluntary isometric contraction values (isoMVC), -13.5% for *Vastus Lateralis* (VL), and -9.6% for the Gastrocnemius Lateralis (GL), as well as with isometric electromyographic values (isoEMG, expressed in % RMS) of 8.3% for VL and 14,1% for GL between "before" and "after" the 2-hour cycling test. At the end of a 30-min cycling exercise at an intensity corresponding to 80% of maximal oxygen uptake ($\dot{V}O_{2max}$) followed by four 60-s periods at 120% of $\dot{V}O_{2max}$, Bentley et al. (2000) also observed a significant decrease in EMGi measured during an isoMVC preformed immediately after and also six hours later. For these authors, the level of exercise stress administered in this study was sufficient to impair the central and peripheral mechanisms of force generation in knee extensors for a period of 6 hours and athletes engaged in concurrent training (strength and endurance) should consider this effect in exercise programming.

Indeed, to improve their specific endurance performance, many competitive endurance athletes such as triathletes and cyclists included strength sessions in their classical endurance training. Accordingly, Paavolainen and al. (1999) showed that simultaneous explosive strength and endurance training produced a significant increase in a 5-km running performance without changes in $\dot{V}O_2max$ or other aerobic power variables in well-trained athletes. This could be due to the enhancement in muscular characteristics which were transferred into improvement in muscle power and running economy. The effects of strength training can also have different consequences. Muscular strength can be increased by changes in the cross-sectional area of muscle from protein synthesis and by neural adaptations that enhance motor unit activation (Sale, 1992). Variations in training intensity and protocol appeared to elicit different neuromuscular adaptations. High loads (3 to 6 maximal repetitions [MR]) and lower volumes were associated with neural adaptations while muscle hypertrophy was produced with lower loads (8 to 12 MR) higher volume resistance training occurred through increased protein synthesis in muscle fibres (Docherty and Sporer, 2000). According to these authors, studies using various experimental protocols have shown that concurrent strength and endurance training resulted in compromised strength gains (Hennessey and Watson, 1994; Hickson, 1980) or uncompromised strength gains (Hunter et al., 1987; McCarthy et al., 1995) while no decrease in endurance capacity was observed, specifically over longer periods of concurrent training or in trained athletes (Hennessey and Watson, 1994). Muscular characteristics may be important for endurance performance (Paavolainen et al., 1999). Heavy resistance strength training has improved the endurance performance of previously untrained subjects (Hickson et al., 1988; Marcinik et al., 1991; McCarthy et al., 1995) as well as the running economy of female distance runners (Johnston et al., 1997), without changes in maximal oxygen uptake ($\dot{V}O_{2max}$). Findings by Mc Carthy et al. (1995) indicate that 3 days per week of concurrent performance in both strength and endurance training does not impair adaptations in strength, muscle hypertrophy, nor in neural activation induced by strength training alone. Significant increases in maximal isometric knee-extension torque were accompanied by non significant ($P \leq 0.07$) increases in root mean squared EMG amplitude of the quadriceps musculature for both S (high-intensity strength training) and CC (concurrent strength and endurance training) groups. Recently, Hansen et al. (2007) have also shown that strength training increased the 1MR in both squat and leg curl and reduced the freely chosen pedal rate during submaximal cycling in healthy subjects.

To the best of our knowledge, no data are available focusing on the effect of this type of concurrent training on cycling performance in well-trained triathletes. Therefore, the purpose of the present study was to examine the effects of a regime of maximal strength training in combination with a usual endurance training programme on the physiological and muscular parameters during a 2-hour constant cycling test in well-trained triathletes. The main hypothesis tested is that a 5-week period of strength training allowed triathletes to maintain the freely-chosen-cadence in cycling during a long duration ergocycle test at a steady-state. Indeed, it is well-known that the stabilization of both cadence and power during a cycling stage could improve the subsequent running performance.

MATERIALS AND METHODS

Subjects. 14 well-trained male triathletes currently competing at the regional and national levels participated in the study (See Table 1). Seven of these subjects were randomly assigned to the endurance-strength training group (ES; *N*=7) and were studied before and after a strength training programme during 5 weeks (three times per week). The remaining seven subjects were assigned to the endurance-only training group (E; *N*=7). Before participating in this study, subjects were fully informed about the protocol modalities (except for the special interest in pedal cadence), and a written consent was given to all subjects before all testing, according to local ethical committee guidelines.

Training Design. The training period lasted 5 weeks and was carried out during the autumn period when the subjects put an end to their competitive season, and when they were not so involved in competition. During that period, for our two groups (ES and E), most of the training was strictly aerobic and performed under 75% of $\dot{V}O_{2max}$. Endurance training in both groups consisted in swimming, cycling and cross-country and/or road running at the intensities below (81%) or above (19%) the second ventilatory threshold (VT_2). The amount of volume of training during the 5 weeks between pre and post assessment is presented in the table 1. In addition to the endurance training, the ES group performed a High Weight Training (HWT) session using lower limb muscles three times per week. The exercise programme was designed exclusively to increase leg strength. Workouts consisted of two progressive warm-up sets followed by three to five sets to failure of 3-5 repetitions and exercises focused exclusively on quadriceps (leg extension, leg press), hamstring (hamstring curl), and calf muscles (leg curl). The sets were separated by 3-min rest periods. The training programme was periodized and the loads were calculated > 90% one maximal repetition (1MR) and were progressively increased to maintain that range of repetitions per set. Finally, reassessment of 1MR was completed by the ES group every 2 weeks to maintain maximal loads over the whole training period: the training load was then recalculated in accordance with the new value of 1MR. The subjects also did dead lifts and sit-ups to strengthen their back and abdominal muscles, so as to prevent injury. All training sessions were supervised.

Experimental overview. Before and after a controlled training period of 5 weeks, all subjects performed cycling and muscle function tests. The first test involved an incremental cycling test to exhaustion to determine maximal oxygen uptake ($\dot{V}O_{2max}$), power associated with $\dot{V}O_{2max}$ (Pmax) and power associated to the first ventilatory threshold (P_{VT1}). The second test was a maximal concentric lower-limb strength measurement. The third session of the test consisted in a 2h constant cycling exercise where isometric strength measurements were done immediately before and after.

Cycling Ergometer. All experimental cycling tests were conducted on an electromagnetically braked ergocycle (Lode, type Excalibur, Gröningen, The Nederland) at the self-selected cadence. The ergometer allowed subjects to maintain the power output constant independent of cycling cadence.

EMG signal measurements. Surface EMG activity was continuously recorded for the following 2 muscles of the right lower limb: rectus femoris (RF) and vastus lateralis (VL). A pair of surface pre-gelled Ag/AgCl electrodes (Medicotest, type Blue Sensor, Denmark, Sensor) was attached to the skin with a 20-mm inter-electrode distance. The electrodes were placed longitudinally with respect to the underlying muscle fibre arrangement and located according to the recommendations by **SENIAM** (Surface EMG for Non-Invasive Assessment of Muscles) (Hermens et al., 2000; Rainoldi et al., 2000). A common reference electrode was placed over the anterior superior spine of the iliac crest. Prior to electrode application, the skin was shaved and cleaned with alcohol in order to minimize impedance (The impedance was checked, and only values below 1000 Ω were accepted). The signal was preamplified (Gain x 600), band pass filtered with cut-off frequency of 5/500 Hz and saved on a computer. EMG data were collected with an acquisition card, digitised using a 1 kHz sampling rate and stored on computer (software Origin 6.1). Subsequently, from the raw EMG of each muscle a linear envelope of the muscle activity was created using a 4th order Butterworth digital filter with a cutoff frequency of 5 Hz. A preliminary assessment of the EMG data conidered cutoff frequencies between 3 and 15 Hz, and the maximal efforts were considered similarly. It was concluded that 5 Hz provided sufficient smoothing of the raw data to obtain mean data for both groups without attenuating significant characteristics of the EMG signals. From the linear envelopes the integrated EMG signal was calculated (iEMG) and all iEMG data were normalised (normalised iEMG) by dividing the value of each muscle by its own EMG value obtained during the maximal voluntary contraction (MVC) (period of 500 ms) performed before starting the 2-hour cycling exercise. Consequently, iEMG values were analysed between the 5th and the 20th minutes (period 1: P_1), between the 55th and the 70th minutes (period 2: P_2) and between the 105th minutes and the end of the test (period 3: P_3). Then, the iEMG was calculated at 20-s intervals for a period of 15 min. During the isometric strength measurement test, EMG data were respectively collected from the VL and RF muscles during extension movement of the right lower limb.

Maximal oxygen uptake ($\dot{V}O_2$max) and ventilatory threshold (VT) determinations. After a 48-hour restriction upon strenuous physical activity, each of the 14 subjects performed a continuous, incremental cycling test on the electromagnetically braked ergocycle (Lode, type Excalibur, Gröningen, The Netherlands). The test began with a warm-up of 100 W lasting 6 min, then) the power output was increased by 30 W a minute until volitional exhaustion. During the protocol, $\dot{V}O_2$, expiratory flow ($\dot{V}_E$), respiratory exchange ratio (RER) and heart rate (HR) were continuously recorded breath by breath and averaged every 10 seconds using a telemetric system collecting gas exchanges (Cosmed K4b^2, Roma, Italy). The criteria used for the determination of $\dot{V}O_{2max}$ were a plateau in $\dot{V}O_2$ despite an increase in power output, a RER above 1.1 or a HR over 90% of the predicted maximal HR (Howley et al., 1995). The $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_2$ attained in three successive 10 sec (Billat et al., 2000). In addition, ventilatory thresholds (VT_1 and VT_2) were determined by using the method described by Wasserman et al. (1973) and Reinhard et al. (1979) based on the identification of breakpoints in the evolution of the ventilatory equivalents for O_2 and CO_2. Visual evaluation to determine VT was carried out independently by three experienced investigators. Gross Efficiency (GE) was calculated as the ratio of work accomplished to energy expended (expressed in percentage), using the $\dot{V}O_2$ and energy equivalent for oxygen corresponding to each respiratory exchange ratio value from the tables by Péronnet and Massicotte (1991) (cf. Chavarren and Calbet, 1999).

Maximal concentric lower-limb strength measurements. The evaluation of maximum strength, represented by the load lifted up one and only one time (1 RM), was achieved using a lower limb press with a 45° inclination (Hand press, Multi-form, La Roque d'Anthéor, France). The position of the feet on the platform was adjusted so that the joint angle between the leg and the thigh was 90°. From this initial position, the subjects were asked to perform an extension with their lower limbs, with standard conditions of performance. Before the test began, the subjects were familiarised with the machine and specific technical moves (Stone and O'Bryant, 1987). After a standardised warm-up, the subject's near maximal resistance was estimated. The resistance was then gradually increased until the subject was only able to lift the resistance once (1MR) and not twice. This was recorded as the subject's 1 RM (Mero et al., 1989). There was at least 5 minutes' recovery between each trial.

Isometric strength measurements. Before starting the 2-hour cycling test, subjects were placed in a seated position and were securely strapped into the test chair to perform a right isometric knee extension using an isometric ergometer (Type: Schnell Trainingsgesäte GmbH, Peutenhausen, Deutschland). Subjects performed three maximal isometric contractions of short duration (2–3 sec) using the knee extensor muscles. The maximal force under extension movement (starting position corresponded to thigh/shank angle of 90°) was measured using a strength sensor and the best performance consecutive to the three trials was selected as the maximal isometric voluntary contraction (isoMVC).

Rating of perceived exertion (RPE): Subjects were provided with a typewritten set of standardised directions for the use of Ratings of Perceived Exertion (Borg, 1970). Subjects were instructed to give an overall RPE immediately at the end of each measurement) period during the 2-hour cycling test.

2h cycling test: Before the study, few attempts of intensity manipulation were performed in order to target the precise power output. Accordingly, the VT_1 + 5% intensity was defined as too high in respect to the accomplishment of the 2-hr cycling task. The intensity of VT_1 + 3% was then accepted as a definitive intensity for the experimental procedure (ES: 244.1 ± 14.1W and E: 237.3 ± 36.5W). The test consisted in sustaining this constant power output for 2-hour (excluding a 10 min warm-up at 33% of Pmax) at a free chosen cadence. The interval between the calculations of respiratory parameters was set at 10 s (breath by breath) using the Cosmed $K4b^2$. Data ($\dot{V}O_2$, GE, $\dot{V}_E$, RER, HR, RPE, iEMG and the pedalling cadence) were recorded and analysed between the 5th and the 20th minutes (period 1: P_1), between the 55th and the 70th minutes (period 2: P_2) and between the 105th minutes and the end of the test (period 3: P_3); this was done in order to give the cyclists a maximal amount of respiratory comfort and to enable them to drink during the test. Cycling cadence was continuously recorded and heart rate was monitored using a cardio frequency meter (Polar, X Vantage, Finland) connected with the telemetric device of the Cosmed $K4b^2$. The EMG parameters of the VL and RF muscles were recorded during the last 3 minutes of the 3 periods (P_1, P_2 and P_3). No feedback was given to the subjects concerning their self-selected cadences during the entire experiment. Indoor air temperatures ranged from 19 to 21°C. Two fans were placed in front of the ergocycle to reduce sweating during cycling and to keep the triathletes cool. Subjects drank on average 1000 mL of water (H_20) per hour during the experiment.

Statistical analysis: All data were expressed as mean ± Standard Deviation (SD). Kolmogorv-Smirnov tests were conducted before statistical analysis and confirmed that all data were normally distributed. Subsequently, a two-factor (training group x period) ANOVA with repeated measures was performed to compare the following variables measured before and after the 5-week training period: $\dot{V}O_2$, GE, $\dot{V}_E$, RER, HR, RPE, EMGi and the pedalling cadence during the 2h-cycling test. A two-factor (training group x time) ANOVA with repeated measures was performed to compare the pre post $isoMVC_{VL}$ and $isoMVC_{RF}$ values before and after the 2-hour cycling exercise. Post-hoc analyses (Newman-Keuls) were used to test differences among pairs of means when appropriate. The accepted significant level of difference was set at $P < 0.05$ for all tests. Statistical analyses were performed using GraphPad InStat software for Windows (GraphPad InStat, version 3.06, GraphPad Software, San Diego California, USA).

RESULTS

The main characteristics of the triathletes are presented in Table 1. No difference was observed in the morphological and the training parameters between the endurance-strength training group (ES) and the endurance only training group (E) during the period studied. The 1 MR (Maximal Repetition) did not differ between the two groups, before training (290.7 ± 50.3 kg and 289.3 ± 38.3 kg, from ES and E, respectively) and after training (310.0 ± 55.6 kg and 277.9 ± 42.1 kg, from ES and E, respectively). However, the 1 MR value obtained after training was significantly higher (+6.6 ± 3.9%; $P<0.01$) than the one recorded before training in ES group; moreover, the 1 RM value obtained after training was significantly lower (-4.1 ± 3.0%; $P<0.01$) compared with the value before training in E group.

Tables 2 and 3 show the effects of the five weeks of training on the physiological variables during the incremental cycling test to exhaustion and the 2h constant cycling test, respectively. $\dot{V}O_{2max}$, HR_{max}, P_{max} and the $\dot{V}O_2$, HR and power values measured to VT_1 and VT_2 did not differ between the two groups before training and remained unchanged with training in the two groups.

In our study, the pedalling cadence was the main result that we were able to observe during the continuous 2-hour test (Figure 1). The analyses of variance show a significant period effect ($P<0.01$) for ES and E in pre and post training. If the cadence registered by the end of the period is significantly lower than the one registered in the middle (P_2; $P<0.05$) or at the beginning (P_1; $P<0.01$) of the test for ES and E in pre-training, its evolution is different in post-training for ES group. After training, the FCC for ES, which significantly decreases (-12.7 ± 7.1%, $P<0.01$) during the first hour of the task, gets steadier later, from P_2 (70.6 ± 9.8 rpm) to P_3 (69.1 ± 7.5 rpm), whereas the E group pedalling cadence decreases significantly all along, during the 2-hour task (-6.9 ± 4.1% from P_1 to P_2 ; $P<0.05$ and –11.2 ± 8.9% form P_2 to P_3, $P<0.01$).

Table 4 shows the effects of training on the electromyographic variables measured before and after the 2-hour constant cycling test. Both $isoMVC_{VL}$ and $isoMVC_{RF}$ measured before the 2-hour constant cycling test were significantly ($P<0.01$), lower than $isoMVC_{VL}$ and $isoMVC_{RF}$ measured after the 2-hour cycling test, in pre- and post- training for the two groups. Post-training $isoMVC_{VL}$ (before: 100.3 ± 17.9; after: 91.9 ± 14.9 N.m) and $isoMVC_{RF}$ (before: 99.2 ± 16.4; after: 89.2 ± 11.6 N.m) were significantly ($P<0.05$) higher than pre-training $isoMVC_{VL}$ (before: 92.5 ± 16.4; after: 83.9 ± 14.6 N.m) and $isoMVC_{RF}$ (before: 92.6 ± 14.8; after: 81.1 ± 8.6 N.m) for ES. The $isoMVC_{VL}$ and $isoMVC_{RF}$ values did not differ significantly between ES and E in pre-training. However, after training, the test values before the 2-hour constant cycling did not differ significantly while those measured after are significantly higher ($P<0.05$) than ES as opposed to E, as well as for $isoMVC_{VL}$ (91.9 ± 14.9 vs. 76.6 ± 7.2 N.m) and for $isoMVC_{RF}$ (89.2 ± 11.6 *vs.* 76.5 ± 9.6 N.m).

The changes over time of the integrated EMG signal of VL ($EMGi_{(VL)}$) and RF ($EMGi_{(RF)}$) for the two groups are presented in Figure 2 and Figure 3. ANOVA shows a significant period effect ($P<0.01$) for ES and E in pre- and post- training. Values did not differ between the two groups before and after training and remained unchanged with training in E. However, after training, EMGi $_{(RF)}$ (P_2: 34.7 ± 3.2 %; P_3: 40.6 ± 4.1 %) was significantly lower ($P<0.05$) than EMGi $_{(RF)}$ before training (P_2: 39.6 ± 6.2 %; P_3: 43.5 ± 5.7 %) in ES. Moreover, the variations over time of EMGi $_{(VL)}$ during the 2-hour constant cycling test changed with training in ES group. Indeed, after training, EMGi $_{(VL)}$ values measured in P_3 (43.4 ± 8.3 %) did not differ any longer with EMGi $_{(VL)}$ values measured in P_2 (42.4 ± 8.4 %).

DISCUSSION

The results of the present study showed that an additional heavy strength training associated with usual endurance training induced changes in biomechanical (cycling cadence) and muscular variables, but not in metabolic variables ($\dot{V}O_2$, GE, RER, $\dot{V}_E$, HR) and perceived exertion values during a two-hour constant cycling task performed in laboratory conditions by well-trained triathletes.

CHANGE IN MAXIMAL STRENGTH WITH TRAINING. In the present study, the triathletes of the ES group achieved significant gains in 1 RM leg press after 5 weeks of concurrent training (+6.6 ± 3.9% ; $P<0.01$) whereas the E group presented a significant decrease (-4.1 ± 3.0%; $P<0.01$) in maximal strength after the training period. Nevertheless, no variation in body mass was observed in subjects of either group, after the five weeks of training. Supporting the existing literature (Bigard and Koulmann, 2006; Docherty and Sporer, 2000; Moritani and De Vries, 1979; Narici et al., 1989; Sale, 1988, 1992; Thorstensson et al., 1976), we can suppose that our 5-week strength training protocol did not induce muscular hypertrophy. We have also observed that the isoMVC values recorded before the 2-hour cycling test for ES group were significantly more important than in the post test as opposed to pre test (+ 8,1% for VL, $p<0.01$ and + 7,1% for RF, $p<0.01$). The increase in isoMVC obtained at the end of the 5 weeks of combined training was associated with an increase in EMG activity for VL (+ 7,7%, $p<0.05$) as well as for RF (+ 8,8%, $p<0.01$). These results are in agreement with the study by Gabriel et al. (2006) who emphasizes the fact that strength gains in the early phase of a strength training program are associated with an increase in the amplitude of EMG activity. Therefore, the strength gained by the ES group is probably due to central adaptations (increased activation, more efficient recruitment, more efficient motor unit synchronisation, more efficient excitability of the α-motor neurons, and decreased Golgi tendon organ inhibition) (Sale, 1992). Indeed, variations in training intensity and volume appeared to elicit different neuromuscular adaptations. High load and lower volume (i.e. three to five sets to failure of 3-5 repetitions, with a load > 90% 1MR, like in our study) are associated with an increase in force generation without an increase in muscle size, and are related to neural adaptations (Docherty and Sporer, 2000). The gains in 1MR were lower than the improvements showed in previous studies [22% for 1 RM squat (McCarthy et al., 1995); 22.5%for 1 RM squat, (Bishop et al., 1999); 25% in the half squat and 17% in the calf raise, (Millet et al., 2002); 19.5% in the leg press (Kraemer et al., 1995); 27% in parallel squat (Hickson, 1980)]. These observations have to be related with the period of time of our study: pre-tests were performed by subjects who were fit immediately after the competitive season, as opposed to the post-tests performed after five weeks of low intensity endurance training (i.e. a low percentage of maximal aerobic power, lower than 75% $\dot{V}O_{2max}$). The decrease in 1RM observed for the control group (E) illustrated that endurance training alone, performed at low intensity, was not efficient enough to maintain the initial level of performance of the subjects. Nevertheless, adding three sessions of strength training per week to this endurance training programme enabled the ES group to improve $isoMVC_{(VL)}$ (+8.4% ; $P<0.01$) and $isoMVC_{(RF)}$ (+7.1% ; $P<0.01$) together with an increase in the maximal strength level ; therefore, enabling them to maintain their performance during the post-tests. Depending on the group (ES or E), and whatever the test period (pre or post training), our results showed a decrease ($P<0.01$) in the isometric maximal voluntary contraction of the VL and RF muscles after a 2-hour cycling test (9 and 16.7%, respectively). These values correspond to those observed in isometric conditions (-13%) by Lepers et al. (2000) after a similar 2-hour cycling test performed at 65% of Pmax but lower than those registered by Sahlin and Seger (1995) after 85 minutes of cycling at a fixed cadence in non expert cyclists (-34%) who were not familiarised with the cycling task.

CHANGE IN PHYSIOLOGICAL VARIABLES. $\dot{V}O_{2max}$, HR_{max}, P_{max} and the $\dot{V}O_2$, HR and power values measured to VT_1 and VT_2 remained unchanged with training in the two groups during the incremental cycling test to exhaustion. The results concerning trained subjects are in agreement with the current literature (Bishop et al., 1999; Hickson, 1980; Hickson et al., 1988; Millet et al., 2002). Only Paavolainen et al. (1999) showed an improvement in $\dot{V}O_{2max}$ for trained athletes after they had completed a combined (strength + endurance) nine-week programme. $\dot{V}O_2$, GE, $\dot{V}_E$, HR and RPE values measured to P_1, P_2 and P_3 during the two-hour cycling task also remained unchanged with training in the two groups. In accordance with the present findings, previous studies have typically reported no change in $\dot{V}O_2$ (Bishop and Jenkins, 1996; Hickson et al., 1988; Marcinick et al., 1991) in response to strength training. Following a combined 12-week training programme including a usual aerobic training associated with two strength training sessions per week, Bishop and Jenkins (1996) showed that for 14 trained female cyclists, there was no improvement in peak $\dot{V}O_2$, lactate threshold and endurance performance (characterised by a one hour cycling task) in spite of a significant improvement in the maximal strength level of the lower limbs (+35.9%; $P<0.01$). On the contrary, Hickson et al. (1988) reported that resistance training three times per week during 10 weeks improved endurance cycling performance (+20% time to exhaustion) in endurance trained male subjects, despite a lack of changes in $\dot{V}O_2$, oxidative enzyme activity or fibre composition. Marcinik et al. (1991) also showed that a strength training programme (3 times per week during 12 weeks) could increase endurance performance on an ergocycle independently of an increase in $\dot{V}O_{2max}$. According to these authors, increases in leg strength, rather than metabolic adaptations, were responsible for the improvements in endurance performance after strength training. Nevertheless, in our study, the increase in the maximal strength of the lower limbs did not trigger any increase in endurance performance. No modification was noticed after the five weeks of combined training regarding the various physiological parameters registered during the 2-hour cycling test. The gains in strength measured in our study were much lower than those measured in the two previous studies referenced below [+27% in squat and +25% in leg extension (Hickson et al., 1988); + 30% in leg extension, (Marcinik et al., 1991)], and were not efficient enough to induce an increase in endurance performance.

The 2-hour cycling task elicited an increased in $\dot{V}O_2$ (P<0.05), which is an indicator of metabolic efficiency and cycling economy when power output is constant. In agreement with the study by Lepers et al. (2000), all the other parameters such as RER, $\dot{V}_E$, RPE and heart rate were also significantly higher during P_2 and P_3 than during P_1 (Table 3) and remained unchanged with training. An increase in energy cost with exercise duration had already been observed for prolonged exercises such as running (Davies and Thompson, 1986) or triathlon (Hausswirth et al., 1996), but relatively few data exist concerning prolonged cycling exercise. The progressive and continuous increase in $\dot{V}O_2$ values during the 2h task can be linked to several factors: a drift in the temperature of the subjects (Saltin and Stenberg, 1964), thermoregulation (Galloway and Maughan, 1997) and an increase in the sudoral gland activity combined with a decrease in the phosphagene way efficiency. The use of lipids as substrates is also known to increase the $\dot{V}O_2$ requirement of exercise (Hausswirth et al., 1996). Therefore, RER was found to decline significantly (P<0.01), which suggested that the energy source was gradually switched from carbohydrate to fat substrates during the 2-hour exercise.

CHANGE IN THE EVOLUTION OF FCC: The changes over time of the pedalling cadence during the 2-hour cycling task changed after five weeks of concurrent training. Before training, our results were close to those obtained in previous studies that emphasize a significant drop in the pedalling cadence due to the prolonged exercise. For exercises lasting over 30 minutes, several authors reported a significant decrease in the FCC of 12.3% ($P<0.01$) after 1h pedalling (Vercruyssen et al., 2001) and a decrease ranging from 19 to 21% ($P<0.01$) after 2-hour pedalling (Argentin et al., 2006; Lepers et al., 2000). The decrease in FCC relative to the duration of the exercise is specific to triathletes and was characterised by a new organisation of the pattern movement linked to an optimisation of the metabolic cost (Lepers et al., 2000). In contrast to the performance of an isolated cycle task, the triathlete may save some energy during the cycle session of a triathlon in anticipation of the succeeding run (Argentin et al., 2006). According to the progressive decrease ($P<0.01$) in FCC and the progressive increase ($P<0.01$) of $EMGi_{(VL)}$ and $EMGi_{(RF)}$ throughout the 2-hour cycling at constant power, the muscular strategy which consisted of greater forces applied to the pedals with a reduction in the pedalling rate (Patterson et Moreno, 1990) as the exercise duration increased, appeared to contradict results regarding a decrease in post exercise maximal muscular strength. A change in muscular type fibre recruitment during the 2-hour cycling exercise is often put forward. According to Ahlquist et al. (1992), a decrease in FCC observed with exercise duration in the present study could indicate that type II fibres were increasingly recruited. Woledge (1998) mentioned the change in recruitment from Type I to Type II fibres during prolonged exercise. It could explain changes in $\dot{V}O_2$ with exercise duration in association with a decrease in FCC. This may lead to a decrease in thermodynamic muscle efficiency and consequently an increase in metabolic cost. In relation to our results and to others (Argentin et al., 2006; Lepers et al., 2000), one hypothesis relates to the increase in $\dot{V}O_2$ from P_1 to P_3 to the additional recruitment of type II muscle fibres.

After five weeks of concurrent training, the progressive and continuous decrease in FCC observed in pre-training is replaced by a steady FCC for the ES group during the second hour of exercise, from P_2 (70.6 ± 9.8 rpm) to P_3 (69.1 ± 7.5 rpm). The upholding of a constant pedalling cadence during the second hour of the task was observed with a stabilisation of the $EMGi_{(VL)}$ values, in accordance with Patterson and Moreno studies (1990). Alquist et al. (1992) suggested that force development, as opposed to velocity contraction, determines the degree of type II fibre recruitment. In the present study, according to this hypothesis, a stabilisation of FCC observed during post-training 2-hour cycling exercise could indicate that recruitment of type II fibres were stabilised. Progressive recruitment of type II fibres all along the exercise triggers a progressive increase in $\dot{V}O_2$ (Argentin et al., 2006; Lepers et al., 2000; Woledge, 1998). In this study, although the stabilisation of FCC is not associated with a stabilisation of physiological parameters such as $\dot{V}_E$ or $\dot{V}O_2$, all these parameters have not been modified by concurrent training as such ; it appears that the stabilisation of the $EMGi_{(VL)}$ values could explain the stabilisation of cadence.

In conclusion, the results of this study confirm the decrease in FCC during a 2-hour constant cycling task. This decrement could be mainly related to the occurrence of muscular fatigue, resulting into a change in neural and contractile properties in the quadriceps muscle. One interesting finding in this study is that a combined endurance and strength training improve the level of maximal isometric force in triathletes and prevent the decrease in the cadence mostly observed due to exercise duration.

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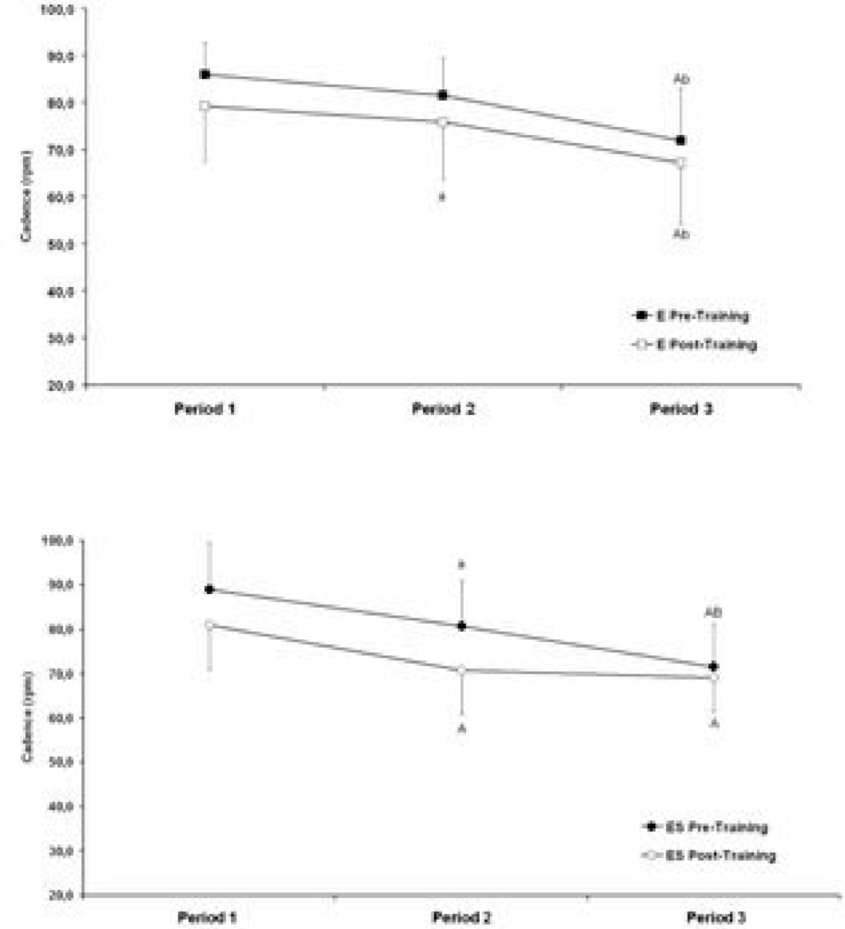

FIGURE 1 - Evolution of the cadence during the 2h-constant cycling test, before (black) and after (white) training in the endurance-strength (ES: black and white circles) and endurance-only (E: black and white squares) groups. ^{A} P<0.01; ^{a} P<0.05 for differences with P1. ^{B} P<0.01; ^{b} P<0.05 for differences with P2.

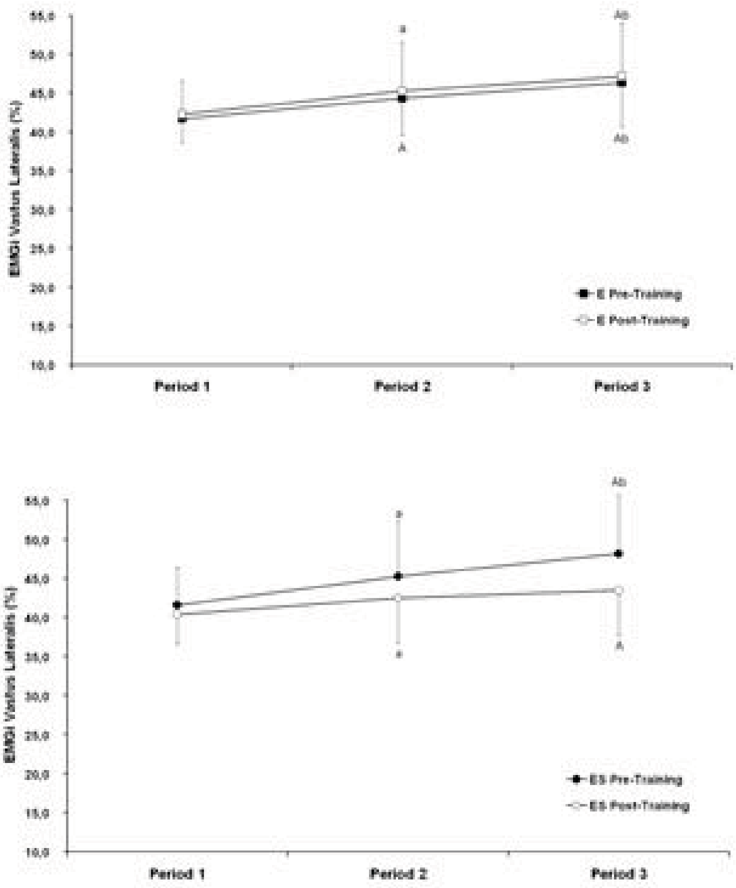

FIGURE 2 - Evolution of the EMGi of the Vastus Lateralis during the 2h-constant cycling test, before (black) and after (white) training in the endurance-strength (ES: black and white circles) and endurance-only (E: black and white squares) groups. ^{A} $P<0.01$; ^{a} $P<0.05$ for differences with P1. ^{B} $P<0.01$; ^{b} $P<0.05$ for differences with P2.

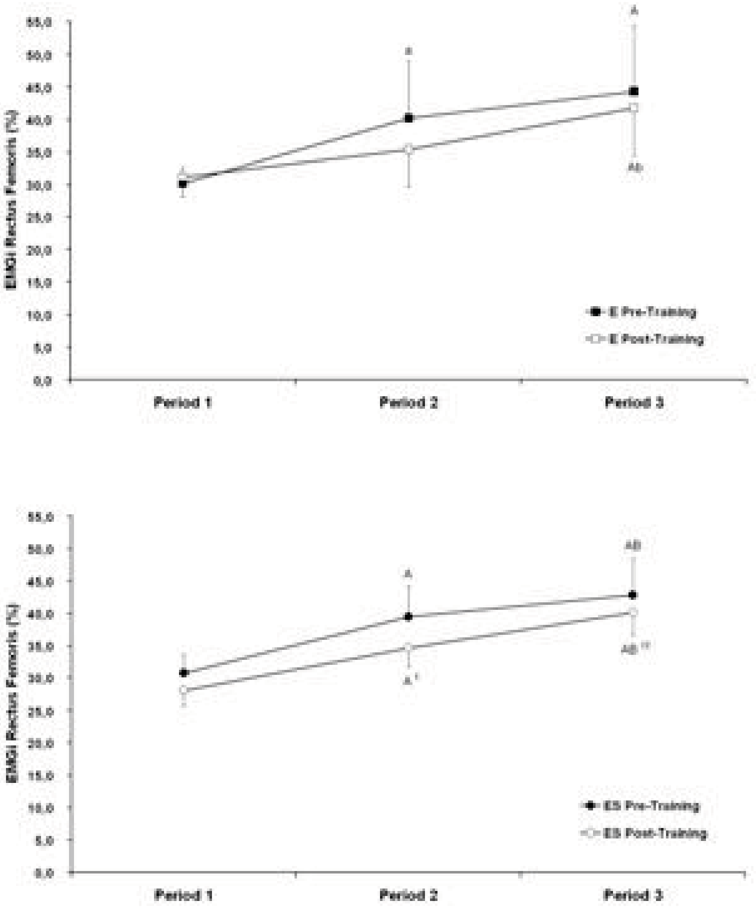

FIGURE 3 - Evolution of the EMGi of the Rectus Femoris during the 2h-constant cycling test, before (black) and after (white) training in the endurance-strength (ES: black and white circles) and endurance-only (E: black and white squares) groups. ^{A} P<0.01; ^{a} P<0.05 for differences with P1. ^{B} P<0.01; ^{b} P<0.05 for differences with P2. $^{\Omega}$ P<0.01; $^{\epsilon}$ P<0.05 for differences between Pre and Post Training.

Table 1. Main characteristics of the endurance-strength (ES) and endurance-only (E) triathletes.

		ES (*N* = 7)	E (*N* = 7)
Age	(year)	30.2 ± 4.3	32.4 ± 4.8
Height	(cm)	176.3 ± 3.1	175.0 ± 7.2
Body mass pre	(kg)	70.4 ± 8.0	69.4 ± 7.8
Body mass post	(kg)	69.9 ± 7.1	69.6 ± 8.0
1 RM pre	(kg)	290.7 ± 50.3	289.3 ± 38.3
1 RM post	(kg)	310.0 ± 55.6^{C}	277.9 ± 42.1^{c}
Total training	(year)	8.7 ± 2.9	8.0 ± 3.2
Volume of training during the 5 weeks pre-assessment			
Swim training	(h week^{-1})	2.7 ± 2.6	3.0 ± 2.2
Bike training	(h week^{-1})	10.4 ± 3.0	10.0 ± 4.3
Run training	(h week^{-1})	4.0 ± 0.6	4.4 ± 1.1
Amount training	(h week^{-1})	17.1 ± 3.1	17.4 ± 3.7
Volume of training during the 5 weeks between pre- and post-assessment			
Swim training	(h week^{-1})	1.5 ± 1.4	1.9 ± 1.4^{c}
Bike training	(h week^{-1})	6.9 ± 2.6^{C}	6.7 ± 3.2^{C}
Run training	(h week^{-1})	3.3 ± 0.9^{c}	3.3 ± 0.8^{c}
Amount training	(h week^{-1})	11.7 ± 3.7^{C}	11.9 ± 3.1^{C}

Values are means ± SD. Pre, pre-training; post, post-training; 1 RM, one repetition maximal on leg press.$^{C}P < 0.01$; $^{c}P < 0.01$ for differences between pre- and post-training.

TABLE 2. Measured parameters during the incremental cycling test to exhaustion, in Pre and Post training in the endurance-strength (ES) and endurance-only (E) triathletes.

			ES (*N*=7)		E (*N*=7)	
			Pre training	Post training	Pre training	Post training
Maximal values	$\dot{V}O_{2max}$	*($mL.min^{-1}.kg^{-1}$)*	69.9 ± 6.3	70.8 ± 5.5	68.4 ± 10.7	68.3 ± 10.1
	$\dot{V}O_{2max}$	*($L.min^{-1}$)*	4.9 ± 0.4	4.9 ± 0.4	4.7 ± 0.8	4.7 ± 0.7
	HR_{max}	*(bpm)*	188.6 ± 14.3	188.0 ± 15.1	184.4 ± 4.6	184.6 ± 5.8
	Pmax	*(Watts)*	412.9 ± 28.0	419.3 ± 29.6	417.1 ± 51.5	410.7 ± 44.8
Values to VT_2	$\dot{V}O_2$	*(% $\dot{V}O_{2max}$)*	84.4 ± 6.1	84.1 ± 4.4	86.3 ± 4.7	84.3 ± 6.1
	HR	*(% HR_{max})*	91.2 ± 1.8	90.5 ± 3.2	92.1 ± 2.7	92.2 ± 3.2
	P	*(% Pmax)*	78.3 ± 4.4	77.7 ± 3.8	77.7 ± 6.3	76.9 ± 5.2
Values to VT_1	$\dot{V}O_2$	*(% $\dot{V}O_{2max}$)*	67.9 ± 5.6	66.6 ± 7.5	69.2 ± 5.8	67.6 ± 5.5
	HR	*(% HR_{max})*	78.9 ± 4.3	77.9 ± 4.7	81.2 ± 3.6	81.7 ± 3.3
	P	*(% Pmax)*	57.5 ± 2.4	56.6 ± 2.5	55.1 ± 4.1	54.3 ± 3.1

Values are means ± SD. $\dot{V}O_2$, oxygen uptake; Pmax, maximal aerobic power ; VT_1, first ventilatory treshold; VT_2, second ventilatory treshold; HR, heart rate; P, power.