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EMG Activity Does not Change During a Time Trial in Competitive Cyclists

Abstract

The purpose of the present study was to measure the electromyographic (EMG) activity of four lower limb muscles and the propulsive torque during a cycling time-trial (TT). Nine competitive cyclists ($\dot{V}O_{2max}$: 73.8 ± 5.3 ml · min^{-1} · kg^{-1}) performed two tests separated over a one-week period on a friction-load cycle ergometer equipped with a SRM crankset scientific system: 1) a continuous incremental test for the determination of the peak power output (PPO); and 2) a 30-min TT test at a self-selected work intensity. The EMG activity of the vastus medialis (VM), the rectus femoris (RF), the biceps femoris (BF), and the gastrocnemius medialis (GAS), and the propulsive torque were recorded every 5 min for 10 s. There was no time effect on the power output, the pedalling cadence, and the mean propulsive torque. The EMG activity of the VM and the RF muscles was unchanged during the TT ($p > 0.05$). The EMG activity of the two knee flexor muscles (BF and GAS) tended to increase with time but it was not significant ($p > 0.05$). The EMG/torque of the VM and the RF muscles tended to decrease with time but it was not significant ($p > 0.05$). The lack of increase in the EMG activity of the four investigated muscles seems to indicate that the subjects performed the TT test at a muscular work steady-state.

Key words
Cyclists · self-paced race · SRM · EMG · propulsive torque

Introduction

It is well known that surface electromyography (EMG) may be used to quantify the total activity of working muscles and to estimate muscular fatigue non-invasively. An increase in EMG amplitude during submaximal dynamic exercises has been shown to reflect the recruitment of additional motor units (MU) and/or an increase in MU firing rate to compensate the deficit in contractility resulting from impairment of fatigued MU [17]. Several previous studies [8,17,19] have reported that a progressive increase in EMG activity of the knee extensor muscles occurs during a high-intensity cycling exercise. Housh et al. [8] found a significant increase in the vastus medialis (VM) EMG activity for an intensity of 80 – 95% of peak power output (PPO). Similar results were also described by Petrofsky [17] for work loads of 60 – 100% of the maximal oxygen uptake ($\dot{V}O_{2max}$) sustained to fatigue. Saunders et al. [19] found an increase of the vastus lateralis (VL) EMG activity but only for an exercise intensity above the lactate threshold (LT). However, Lucia et al. [11] did not observe an increase of the EMG activity of the VL during a 20-min cycle ergometer test at 77% of PPO, which was performed just above the LT of the subjects (74% of PPO). The differences between these studies are probably due to the fitness level of the subjects. In these previous studies [8,17,19], the subjects were generally untrained cyclists whereas Lucia et al. [11] selected professional cyclists. The authors have suggested that in the professional cyclists the recruited MU were very resistant to fatigue at sub-maximal intensities close to 80% of PPO. Such neuromuscular adaptation is probable after many years of high level training.

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During all these studies [8,11,17,19], the subjects could not choose themselves the level of the intensity because they had to maintain the power output required by the authors. To our knowledge, only two studies [10,20] have examined the lower limb EMG activity during a self-paced cycling time-trial (TT). However, the EMG activity was only measured during "all out" 1 – 4-km bouts performed at regular intervals throughout the exercise. Based on the study of Lucia et al. [11] who found no change in VL EMG activity for 20 min of cycling at 80% of maximal oxygen uptake, it could be assumed that the muscular activation of the quadriceps muscles of well-trained competitive cyclists reaches a steady-state during a TT exercise. This is supported by recent observations that the oxygen consumption and the blood lactate concentration remained stable during a simulated 30-min TT cycling exercise [16].

Although much significant cycling and EMG research includes the knee extensors, considerably less information is available regarding the knee flexors. To our knowledge, the EMG activity of the knee flexor muscles (hamstrings and gastrocnemius) has never been measured during a simulated TT. Information regarding the activity characteristics of the knee flexor muscles along with the knee extensors is important in understanding the muscular strategies cyclists employ to realize a prolonged cycling event at a high power output.

The aim of this study was to analyze the EMG activity of four lower limb muscles, two knee extensor muscles (vastus medialis and rectus femoris), and two knee flexor muscles (biceps femoris and gastrocnemius), and the propulsive torque, in competitive cyclists during a 30-min time-trial laboratory test. We hypothesize that the EMG activity of the knee extensor muscles would not increase with time during a 30-min TT.

Materials and Methods

Subjects

Nine male competitive cyclists (racing experience ranging from 2 to 11 yrs), volunteered for participation in this study. They were classified in national category (n = 6) or in regional category (n = 3) of the French Cycling Federation. The study was approved by the institutional ethics committee and all subjects provided voluntary, informed, written consent before participation. Mean (± standard deviation [SD]) physical characteristics of the subjects were: age, 21 ± 3 yr; height, 176 ± 5 cm; body mass, 66 ± 6 kg. The subjects completed two tests over one week of the competition period. They refrained from any high-intensity and long-duration training 24 h before each test. The two tests were separated by at least two days. All the tests were performed in a climate-controlled laboratory (20 to 23 °C, 45 to 55 % relative humidity). During the first visit, they performed a continuous incremental test to exhaustion. On a second visit, they performed a 30-min time trial (TT) test. High reproducibility has been reported of cycling TTs of short and long duration [7]. During the TT test, the EMG activity and the propulsive torque were measured. The two tests were performed on a friction-load cycle ergometer (Monark 818 E, Stockholm, Sweden), which was equipped with drop handlebars and a racing seat. All subjects used their own clip-in pedals and cycling shoes to control the potential influence of pedal design on pedalling technique and muscle activity patterns. The ergometer had been modified with an adjustable height of both the saddle and handlebars (Ergostem, Look, Nevers, France) to match the cyclist's bicycle geometry. The cycle ergometer was equipped with a scientific SRM crankset system (SRM, Schoberer Rad Messtechnik, Fuchsend, Germany, accuracy = 0.5 %) measuring the power output from the torque and the angular velocity of the crank. The crank length of the SRM was 175 mm. The validity of the power output measured with a SRM was assessed by Martin et al. [14]. Before each TT test, the SRM was calibrated using the manufacturer's recommendations because it can be modified slightly by changes in temperature.

Incremental test to exhaustion

The subjects performed a progressive incremental test to exhaustion to determine the $\dot{V}O_{2max}$ ($l \cdot min^{-1}$, $ml \cdot kg \cdot min^{-1}$), the PPO (W), and the maximal heart rate (HR_{max}, bpm). The test started at a workload of 80 W for two minutes. The load was increased by 20 W each minute until the subject could no longer maintain a pedalling cadence (CAD) of 80 rpm despite verbal encouragements. At all times throughout the test, subjects were required to remain in a seated position. During the test, a breath-by-breath portable gas analyzer (Cosmed $K4b^2$, Rome, Italy) and a chest belt (Polar Electro, Kempele, Finland) were used to collect the metabolic and HR data. The accuracy of the oxygen uptake measurement using the Cosmed $K4b^2$ portable telemetry system versus the CPX Medical Graphics was assessed by Hausswirth et al. [5]. The Cosmed $K4b^2$ system was calibrated using the manufacturer's recommendations. Before beginning each test, the Cosmed $K4b^2$ was warmed up for a period of not less than 45 min. Following this, the system was calibrated with known volumes (3 l syringe) and known concentrations of gas prior (O_2 and CO_2). Oxygen consumption ($\dot{V}O_2$, $l \cdot min^{-1}$), carbon dioxide production ($\dot{V}CO_2$, $l \cdot min^{-1}$), heart rate (HR, bpm), and minute ventilation ($\dot{V}_E$, $l \cdot min^{-1}$) were continuously recorded and averaged every 10 s during the test. The highest $\dot{V}O_2$ mean value obtained during the test was defined as the $\dot{V}O_{2max}$. The PPO was determined as the highest workload fully completed.

Time trial test

The subjects were requested to perform an "all out" 30-min TT exercise (race simulation) on the cycle ergometer. The work intensity was self-selected by each subject. The protocol of the TT test was already described in a previous study [16]. Each subject was allowed to warm up as they normally would before a TT race. After a short rest period, the subjects began to exercise by adjusting their own power output by fine-tuning. Subjects were allowed to freely adjust the work intensity at their convenience throughout the TT test by adjusting the tension of the inertia wheel belt of the Monark and/or the pedalling rate. During the TT test, subjects were required to remain in a seated position to prevent alterations in muscle fiber recruitment patterns that result from changes in posture. Subjects were verbally encouraged to perform the best of their ability throughout each test. Throughout the TT test, power output (PO, W) and HR data on the unit display (SRM powercontrol), which was fixed at the handlebar of the cycle ergometer, were hidden from the subject. Only the pedalling rate (CAD) and the time elapsed were displayed similar to an actual TT performed in the field. The data stored in the SRM powercontrol were thereafter transmitted to a PC via an interface. The PO, the CAD (rpm), and the HR were sampled at 1 Hz during the entire TT test and were averaged between the 5th and the 25th min as proposed by Perrey et al. [16].

Every 5 min, the propulsive torque (PT, N·m) was recorded at 200 Hz and averaged during 10 s. Before each TT test, the torque software was calibrated using the manufacturer's recommendations. The SRM crankset scientific system does not allow a dissociation of the propulsive torque produced by each lower limb. Assuming that the propulsive torque produced during the upstroke does not contribute significantly to the total torque [9], the propulsive torque of the right lower limb was calculated by averaging the torque values between the 0 and 180° crank angle, which corresponded to the push down phase of the right lower limb during the pedalling cycle. All crank torque profiles were analyzed for nadir propulsive torque (PT_{nadir}), peak propulsive torque (PT_{peak}), and the difference between PT_{peak} and PT_{nadir} (PT_{delta}).

The EMG activity was measured from the vastus medialis (VM), the rectus femoris (RF), the long head of biceps femoris (BF) and the medial head of gastrocnemius (GAS) muscles of the right lower limb during the TT test. Pairs of silver/silver chloride bipolar surface electrodes with adhesive collars and electrolytic gel (Skintact, 50 mm diameter), to provide a stable interface between the skin and the recording site, were applied to the muscle, parallel to the muscle fiber arrangement at a constant inter-electrode distance of less than 5 cm. The reference electrodes were placed over on electrically neutral site (vertebra). All the electrodes were fixed on the skin with adhesive pads after careful shaving and cleaning of the area using an abrasive cleaner and alcohol swabs to reduce skin impedance to less than 10 kΩ. Electrode wires were taped to the skin to reduce movement artifact. 10-s samples of the EMG signal were collected every 5 min of the TT test. The EMG signals were sampled at 1000 Hz and pre-amplified with a gain of 2500 using a differential amplifier (Biopac MP30, Biopac Systems Inc. Santa Barbara, USA). The EMG signals were band-pass filtered at 30 – 500 Hz. The raw EMG were full-wave rectified and expressed in microvolts root mean square (RMS, mV) with a time averaging period of 20 ms. The mean power frequency (MPF, Hz) was calculated by Fast Fourier Transform algorithm. The RMS was used as an indicator of the total myoelectric activity of the exercising muscle because it has been previously shown that this computation was highly correlated with the number of active motor units [15]. The MPF is linearly related to the action potential conduction velocity of the muscle fiber [1]. For all subjects and for each muscle, the RMS was averaged during the entire crank cycle. The MPF was also determined using the same procedure.

Determination of the EMG/torque ratio: for the VM and RF extensor muscles, a ratio RMS per right lower limb propulsive torque (EMG/torque) was computed to analyze the relationship between muscle activity and torque over time.

Statistical analysis

Means and standard deviations for $\dot{V}O_{2max}$, PPO, HR_{max}, PO, CAD, and HR were calculated. PO and HR were expressed as percentages of PPO and HR_{max}, respectively. Coefficient of variation (CV) was calculated for each subject for the PO. The RMS and MPF values of each muscle and the EMG/torque ratio of the VM and RF muscles were averaged over 10 consecutive pedalling cycles for all subjects and normalized to the reference values of the first 5-min interval. A one-way (time) repeated measures non parametric test (Friedman) was used to determine differences in PO, CAD, PT, PT_{nadir}, PT_{peak}, PT_{delta}, RMS, MPF, and EMG/torque ratio, during the TT test. A pairwise multiple comparison procedure using Tukey test was conducted to determine the significant differences between the intervals. For all analysis, statistical significance level was set at $p < 0.05$.

Table **1** Mean ± SD for variables obtained during the incremental test

Variables	*$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)*	*$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)*	*PPO (W)*	*HR_{max} (bpm)*
Mean	4.9 ± 0.4	73.8 ± 5.3	388.3 ± 32.5	184.0 ± 6.1

$\dot{V}O_{2max}$: maximal oxygen uptake; PPO: peak power output; HR_{max}: maximal heart rate; VT_2: second ventilatory threshold

Table **2** Mean ± SD for variables obtained during the 30-min TT test

Variables	*PO (W)*	*HR (bpm)*	*CAD (rpm)*
Mean	276.0 ± 30.6	172.8 ± 6.7	100.1 ± 6.5

PO: mean power output; HR: mean heart rate; CAD: mean pedalling cadence

Results

Mechanical and physiological variables

The mean and SD values for the incremental test ($\dot{V}O_{2max}$, PPO, and HR_{max}) and for the TT test (mean PO, HR and CAD) are given in Table **1** and Table **2**, respectively. The PO and the HR represented 74 ± 4.9 % of PPO and 90 ± 4.1 % of HR_{max}, respectively. The mean CV of the PO was 6.0 ± 3.3 %. There was no time effect on PO ($p = 0.94$), CAD ($p = 0.88$), PT ($p = 0.86$), PT_{peak} ($p = 0.37$), PT_{nadir} ($p = 0.99$), and PT_{delta} ($p = 0.89$) during the TT test. Fig. **1** shows the evolution of the propulsive torque profile throughout the TT test. All of the subjects completed the TT test.

EMG activity

The normalized RMS for the four muscles (VM, RF, BF, and GAS) during the TT test is shown in Fig. **2**. The mean RMS of the BF muscle, expressed as the percentage of the 5th min value, increased by 18.3 % between the 5th and the 25th min of the TT test but it was not significant ($p = 0.17$). There was no time effect on the mean RMS for the VM ($p = 0.46$), the RF ($p = 0.46$), and the GAS ($p = 0.30$). Fig. **3** presents the normalized MPF of each muscle during the TT test. The MPF of the VM, expressed as the percentage of the first interval value, increased between the 5th and the 10th min ($p < 0.05$) and between the 20th and the 25th min of the TT test. There was no time effect for the MPF of the RF ($p = 0.23$), the BF ($p = 0.26$), and the GAS ($p = 0.21$) although the MPF of the

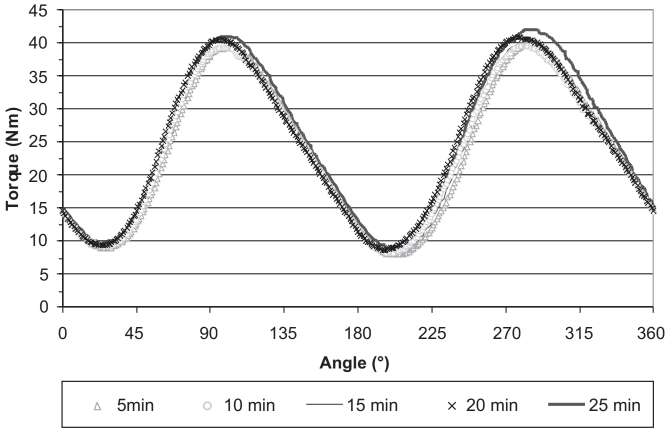

Fig. **1** Propulsive torque profiles for the 5th, the 15th, and the 25th minutes of the TT.

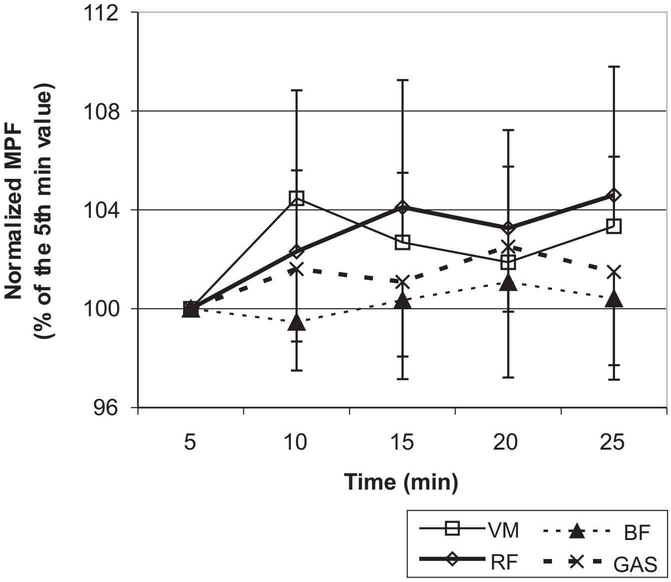

Fig. **3** MPF values, normalized to the value of the 5th min for the vastus medialis (VM), the rectus femoris (RF), the biceps femoris (BF), and the gastrocnemius (GAS) vs. time of the TT test. Vertical lines indicate standard deviations. There was a significant time effect on the MPF for the VM ($p < 0.05$).

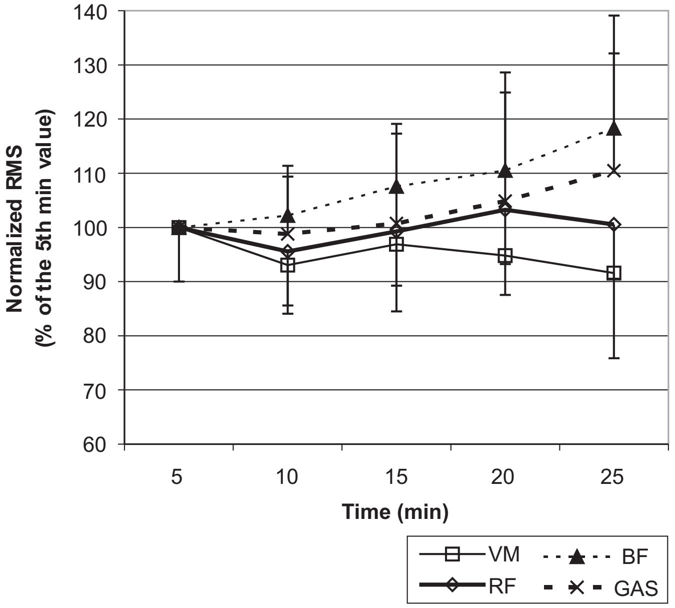

Fig. **2** RMS values, normalized to the value of the 5th min, for the vastus medialis (VM), the rectus femoris (RF), the biceps femoris (BF), and the gastrocnemius (GAS) vs. time of the TT test. Vertical lines indicate standard deviations.

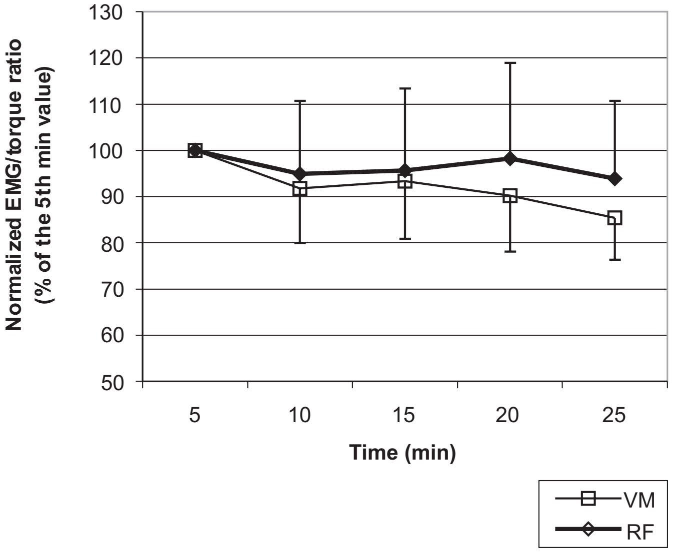

Fig. **4** EMG/torque ratio values, normalized to the value of the 5th min for the vastus medialis (VM) and the rectus femoris (RF) vs. time of the TT test. Vertical lines indicate standard deviations.

RF showed a trend to increase with time. Fig. **4** shows for all subjects the normalized EMG/torque ratio for the VM and RF muscles during the TT test. The EMG/torque ratio of the two muscles, expressed as a percentage of the 5th min value, tended to decrease with time, especially for the VM, but it was not significant ($p = 0.12$ and $p = 0.95$, respectively).

Discussion

The purpose of the present study was to analyze the EMG activity of four lower limb muscles (vastus medialis, rectus femoris, long head of biceps femoris, and medial head of gastrocnemius) in competitive cyclists during a TT test. The main finding of our study was that the activation of the knee extensor (VM and RF) and flexor (BF and GAS) muscles was unchanged during a TT. Theses results support our original hypothesis. The mechanical variables of this study were in accordance with the study of Perrey et al. [16] who used the same TT protocol (Table **3**). It can be assumed that our subjects have performed the 30-min TT in the same way as the subjects of Perrey's study.

In contrast to previous studies [8,17,19], the EMG activity of the quadriceps muscle (VM and RF) did not increase with time during the TT test. In these studies, the increase of the EMG activity was interpreted to be related to the progressive recruitment of additional motor units and/or increased firing rate to compensate for decreased muscle fiber contractility, i.e. "neuromuscular fatigue" [8,17,19]. Thus, as the EMG activity of the VM and RF was unchanged, it seems to indicate that the TT does not induce significant neuromuscular fatigue of the quadriceps muscle in com-

Table **3** Mean ± SD for mechanical variables during 30-min TT between the present study and that of Perrey et al. [19]

Study	*Present study*	*Perrey et al. [19]*
TT power output (W)	276 ± 30.6	234 ± 11
TT power output (% PPO)	74	78
Cadence (rpm)	100 ± 6.5	99 ± 12

petitive cyclists. The difference between our study and the others may be due to the fitness level and cycling experience of the subjects. Theses studies [8,17,19] selected untrained cyclists, who were unable to sustain a high-intensity exercise, whereas the subjects for our study were well-trained cyclists who are familiar with TT exercises at such high intensity. Although the EMG/torque ratio of the VM and the RF tended to decrease, it was not significant. It is difficult to estimate the EMG/torque ratio from our data because the propulsive torque cannot be attributed to a single muscle. However, Kautz et al. [9] have reported that more than 96% of the total torque was produced during the downstroke (0 – 180°) in elite cyclists and it has been shown that the quadriceps muscle is the prime power producer muscle in cycling [2]. An EMG/force ratio increase associated with a constant force is classified as "peripheral" fatigue whereas a constant EMG/force associated with a force decrease is classified as "central" fatigue [6]. Since we have not observed significant changes in EMG/torque ratio for the VM and RF muscles nor a decrease in power output with time, our results suggest that, in competitive cyclists, a TT does not involve peripheral or central fatigue of the quadriceps. Our results show that well-trained cyclists can sustain a high intensity exercise (74% of PPO) without significant changes in MU activation of the quadriceps muscle, indicating that the subjects adjusted their racing pace enough to reach a muscular activation steady-state. These results are in accordance with Lucia et al. [11] who did not observe an increase of the EMG activity of the VL in professional cyclists during a 20-min cycling exercise performed at 77% of PPO (74% of PPO for the present study). In our study, we measured the activity of the VM instead of the VL, however they have been shown to be highly correlated ($r = 0.99$) during cycling exercise [18].

We also observed a significant increase of the MPF of the VM during the start (between the 5th and the 10th min) and a non significant increase at the end (between the 20th and 25th min) of the TT test. According to the findings of Gerdle et al. [3], which showed a linear relation between the MPF and the percentage of active type II fibers of the VL during knee extension exercise, it seems that a shift towards greater use of type II fibers occurred during the TT test. However, other factors (e.g. intra-muscular temperature) may affect the frequency spectrum [4,13]. As muscle temperature was not measured in this study, we cannot discuss the potential contribution of this variable to the increased MPF. Our results are in line with Saunders et al. [19] who found an increase of the VL MPF during a 15-min constant load exercise above the lactate threshold. Moreover, Lucia et al. [12] have found a breakpoint in the RMS-intensity exercise relationship close to the anaerobic threshold in elite cyclists during incremental exercise. The authors have suggested that an additional recruitment of fast fibers occurred close to the anaerobic threshold. The increase of the MPF of the VM at the start and at the end of the TT suggests that a turn-over in fiber recruitment occurs during a high-intensity exercise, which could prevent the neuromuscular fatigue.

To our knowledge, this is the first study to report the EMG activity measure of the knee flexor muscles during a prolonged cycling exercise. As with the knee extensor muscles, the EMG activity level of the BF and the GAS was not significantly modified during the TT test, even if the EMG activity of the BF muscle exhibited a trend to increase with time. The slight increase of the BF muscle could be related to a change in the cyclists' pedalling technique. Takaishi et al. [21] have reported that the EMG activity of the BF was higher in cyclists compared with noncyclists whereas the VL and VM activity was lower. The authors have suggested that the use of positive pedal lifting contributes to alleviate the amount of muscle activity and the muscle stress for the knee extensors of the contralateral limb. In our study, the trend for BF activity to increase may be due to the cyclists pulling up the pedal during the upstroke, and thus produce more propulsive torque as exercise time progresses. Employing this strategy, the subjects could decrease the muscular work of the knee extensors, and thus prevent or delay their potential fatigue, in order to perform the TT test at the highest intensity possible. This may explain the difference between our study and others who observed an increase in quadriceps EMG over time, using untrained cyclists, or subjects who did not use clipless pedals. Nevertheless, it is not clear whether this pedalling technique is commonly employed by well-trained cyclists because BF has a large variability in the activity patterns [18].

Conclusion

The present study showed that the EMG activity of the knee extensor and flexor muscles was unchanged during a 30-min TT in competitive cyclists. Thus, this result seems to indicate that well-trained cyclists are able to sustain a high-intensity exercise while reaching a muscular work steady-state.

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