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SHORT COMMUNICATION

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Occurrence of electromyographic and ventilatory thresholds in professional road cyclists

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Abstract The temporal relationship between the electromyographic (EMG) and ventilatory thresholds was investigated during incremental exercise performed by eight professional road cyclists. The exercise, performed on a cycloergometer, started at 100 W with successive increments of 26 W·min^{-1} until exhaustion. Gas exchange and the root mean square value of EMG (RMS) from eight lower limb muscles were examined throughout the exercise period. Professional cyclists achieved a maximal oxygen consumption, i.e. $\dot{V}O_{2max}$, of 5.4 (0.5) l·min^{-1} [74.6 (2.5) ml·min^{-1}·kg^{-1}, range: 67.8–82.4 ml·min^{-1}·kg^{-1}] and a maximum power (W_{max}) of 475 (30) W (range: 438–516 W). Our results showed at least the occurrence of a first EMG threshold (EMG_{Th1}) in 50% (gastrocnemius lateralis) of the subjects and a second EMG threshold (EMG_{Th2}) in 63% (gastrocnemius medialis). EMG_{Th1} occurred significantly before the first ventilatory threshold (VT_1), i.e. at 52 (2)% and 62 (9)% of W_{max}, respectively. Inversely, no significant difference was observed between the occurrence of EMG_{Th2} and the second ventilatory threshold (VT_2), i.e. at 86 (1)% and 89 (7)% of W_{max}, respectively. These results suggest that the use of EMG may be a useful non-invasive method for detecting the second ventilatory threshold in most of the muscles involved in cycling exercise.

Keywords Cycling · Cycloergometer · Elite cyclists · Progressive exercise · Root mean square

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Introduction

Surface electromyography (EMG) is widely used to quantify the level of activation of working muscles and to detect the prodromic signs of muscle fatigue. For instance, an increase in the root mean square (RMS), an index of global EMG activity, is thought to reflect the recruitment of additional motor units as well as an increase in motor unit rate coding to compensate for the deficit of contractility resulting from the impairment of fatigued motor units (Moritani and DeVries 1978). In incremental cycling exercise, several EMG studies have reported for the quadriceps muscles one (Nagata et al. 1981; Chwalbinska-Moneta et al. 1998) or two (Lucia et al. 1999) EMG thresholds (EMG_{Th}) according to the status of the subjects. These EMG thresholds are explained by an increased contribution of fast twitch motor units to maintain the required energy supply for contraction (Moritani and deVries 1978). However, others studies failed to report EMG thresholds in a similar testing situation (Taylor and Bronks 1995).

In order to correlate neuromuscular, metabolic and ventilatory exercise-induced changes, some studies have investigated the EMG responses to a cycling incremental test performed until exhaustion, and the metabolic and ventilatory changes associated with the increase in power output (i.e. lactate and ventilatory thresholds). Indeed, one would expect the metabolic and ventilatory changes associated with the aerobic–anaerobic transition phase to be associated with muscular changes reflected by non-linear increases in RMS. Following this line, Lucia et al. (1999) showed that the first and the second EMG thresholds were correlated with the first and the second ventilatory thresholds.

However, Jorge and Hull (1986) recorded the EMG activity of eight lower limb muscles during cycling exercise. Each muscle seems to accomplish a specific task according to the subject's capability to push and to pull up the pedal. In studies reporting EMG thresholds, these non-linear changes were not reported for all muscles involved in pedalling but rather for the vastus lateralis (Nagata et al. 1981; Lucia et al. 1999), rectus femoris (Chwalbinska-Moneta et al. 1998; Lucia et al. 1999) and soleus (Chwalbinska-Moneta et al. 1998).

The aim of the present study was first to verify the existence of two EMG thresholds in eight lower limb muscles in a homogenous population of professional road cyclists and, second, to examine the possibility of a simultaneous occurrence of the EMG and ventilatory thresholds.

Methods

Eight professional road cyclists participated in this study [age: 24 (1) years, height: 182 (3) cm, body mass: 74 (4) kg]. They had 11 (3) years experience of competition and had covered an average of 30,000 km (including training and competitions) in the previous season. All subjects volunteered to enter this experimental design approved by the local Ethics Committee and gave their informed consent. They had no recent or old pathology of limb muscles and joints and they were instructed to refrain from intense training during the 2 days before testing. Three of them were members of the French team in the World Championships for professional cyclists in 2002.

The protocol was performed on an electrically braked cycloergometer (Excalibur sport, Lode, The Netherlands). Subjects realized a progressive test during which all respiratory and ventilatory parameters [oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), respiratory exchange ratio (RER), and minute ventilation ($\dot{V}_E$)] were measured. Starting at 100 W, the workload was increased by 26 $W{\cdot}min^{-1}$. Subjects chose their pedalling rate (rpm) freely and wore sport shoes with clipless pedals. This incremental exercise was stopped when the power output could not be maintained.

Throughout the incremental exercise trial, software (Oxycon Beta, Hellige, Germany) computed breath-by-breath data of $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, and the ventilatory equivalents for O_2 ($\dot{V}_E{\cdot}\dot{V}O_2^{-1}$) and CO_2 ($\dot{V}_E{\cdot}\dot{V}CO_2^{-1}$). The first ventilatory threshold (VT_1) corresponded to the power output value at which $\dot{V}_E{\cdot}\dot{V}O_2^{-1}$ exhibited a systematic increase without a concomitant increase in $\dot{V}_E{\cdot}\dot{V}CO_2^{-1}$ and the second ventilatory threshold (VT_2) was determined by using the criterion of an increase in both $\dot{V}_E{\cdot}\dot{V}O_2^{-1}$ and $\dot{V}_E{\cdot}\dot{V}CO_2^{-1}$. Two independent observers detected VT_1 and VT_2 following the criteria previously described.

During the test, electromyographic activity was continuously recorded from eight lower limb muscles: vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), semimembranosus (SM), biceps femoris (BF), gastrocnemius lateralis (GL), gastrocnemius medialis (GM) and tibialis anterior (TA). A pair of surface electrodes (Universal Ag/AgCl electrodes, Contrôle Graphique Medical, France) was attached to the skin with a 2 cm inter-electrode distance. The electrodes were placed longitudinally with respect to the underlying muscle fibre arrangement. Prior to electrode application, the skin was shaved and abraded using sandpaper and cleaned with alcohol in order to minimize the impedance. The wires connected to the electrodes were well secured with tape to avoid artefacts from leg movements.

EMG was recorded with a ME3000P8 amplifier (Mega Electronics, Finland). The raw EMG signals were band pass filtered between 20 and 480 Hz, amplified, an analog-to-digital converted at a sampling rate of 1 kHz. An EMG power spectral density was computed for 2-s sampling periods at fixed intervals throughout the tests, using a Fast Fourier Transform algorithm and the RMS contained in each 2-s spectrum (corresponding to three revolutions at 90 rpm) was calculated in μV. The power output value at the first and the second EMG thresholds (EMG_{Th1} and EMG_{Th2}) were determined as follows: EMG_{Th1} and EMG_{Th2} as the first and second non-linear increases in RMS respectively. Two independent observers detected EMG_{Th1} and EMG_{Th2}.

Statistical analysis

Results are expressed as mean (standard error, SEM). The level of significance was set at $p < 0.05$. A Fisher's exact test was made to compare the percentage of EMG threshold occurrence between the muscles. A repeated measures analysis of variance was used to compare the power output (watts) of occurrence of EMG thresholds for all the recorded muscles. Moreover, for the eight recorded muscles, repeated measures of analysis of variance were used to determine if there was a significant difference between the EMG and ventilatory thresholds expressed in power output (watts) and as a percentage of maximum power output (W_{max}).

Results

Professional cyclists achieved a maximal oxygen consumption, i.e. $\dot{V}O_{2max}$ of 5.4 (0.5) $l{\cdot}min^{-1}$ [i.e. 74.6 (2.5) $ml{\cdot}min^{-1}{\cdot}kg^{-1}$, range: 67.8–82.4 $ml{\cdot}min^{-1}{\cdot}kg^{-1}$] and a W_{max} of 475 (30) W (range: 438–516 W).

For each muscle, the percentage of EMG_{Th1} and EMG_{Th2} occurrence is depicted in Table 1. The Fisher's exact test revealed no significant difference in the percentage of occurrence of the EMG thresholds. There is no significant difference between the muscles for the power output at which the two EMG thresholds occurred. EMG_{Th1} and EMG_{Th2} occurred at 52 (2)% and 86 (1)% of W_{max}, respectively, while VT_1 and VT_2 occurred at 62 (9)% and 89 (7)% of W_{max}. Thus, a significant difference existed between VT_1 and EMG_{Th1} for all recorded muscles, EMG_{Th1} occurring before VT_1. In contrast, no significant difference existed between EMG_{Th2} and VT_2. An example of EMG and ventilatory threshold determination is depicted in Fig. 1.

Discussion

To our knowledge this is the first study to examine, in a homogeneous population of professional road cyclists,

Table 1 Percentage of occurrence of EMG thresholds in the eight recorded muscles

Muscles	Percentage of muscles showing:	
	EMG_{Th1}	EMG_{Th2}
Vastus lateralis	100	100
Rectus femoris	75	75
Vastus medialis	75	88
Semimembranosus	88	100
Biceps femoris	100	100
Gastrocnemius (lateralis)	50	75
Gastrocnemius (medialis)	63	63
Tibialis anterior	88	88

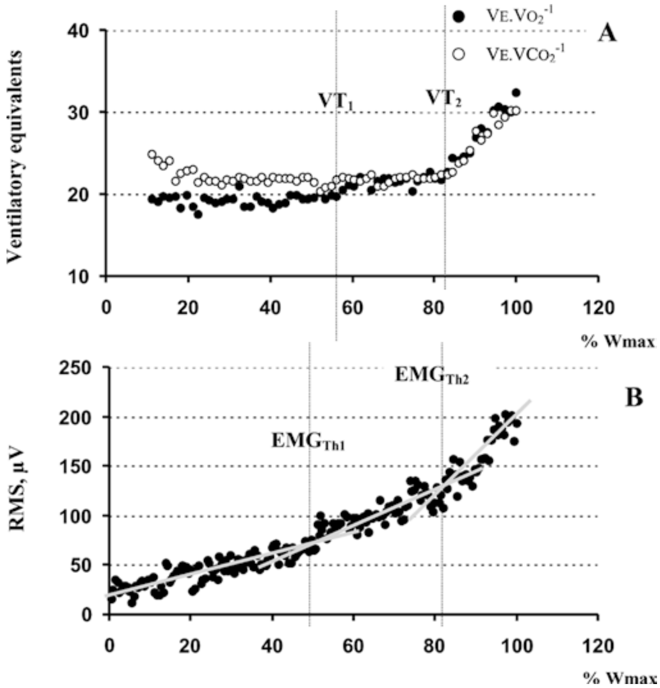

Fig. 1A, B Individual example of evolutions in ventilatory equivalents ($V_E \cdot VO_2^{-1}$, $V_E \cdot VCO_2^{-1}$) (**A**) and RMS (**B**) during incremental pedalling exercise as a percentage of maximum power output (W_{max}). Note that VT_2 and EMG_{Th2} are synchronized while VT_1 and EMG_{Th1} are not. (*EMG_{Th2}* Second EMG threshold, RMS root mean square, VE minute ventilation, VCO2 carbon dioxide production, VO2 oxygen uptake)

the occurrence of EMG_{Th1} and EMG_{Th2} for eight lower limb muscles. Our results showed at least the occurrence of EMG_{Th1} in 50% (GL) of the subjects and in 63% (GM) for EMG_{Th2} (Table 1). EMG_{Th1} occurred significantly before VT_1. In contrast, EMG_{Th2} and VT_2 occurred at the same time.

Based on the assumption of an EMG_{Th}, Lucia et al.(1999) recorded in an elite cyclist population the EMG response of VL and RF, i.e. muscles that are most implicated in pedalling activity. In addition to the classic ventilatory (VT_1 and VT_2) and lactic (LT_1 and LT_2) thresholds, they reported non-linear increases of RMS representing two breakpoints named EMG thresholds 1 and 2. They showed no significant difference between EMG_{Th1}, VT_1 and LT_1 (the first lactic threshold) and between EMG_{Th2}, VT_2 and OBLA ($[La] = 4\ mmol \cdot l^{-1}$). In the present study, two EMG breakpoints named EMG_{Th1} and EMG_{Th2} were found during incremental exercise, and occurred at an exercise intensity of 52 (2)% and 86 (1)% of W_{max}, respectively. In agreement with the results of Lucia et al. (1999), no difference was found between EMG_{Th2} and VT_2. However, differing from the results of Lucia et al. (1999), EMG_{Th1} occurred significantly before VT_1 in the eight recorded muscles. This may be explained by the fact that VT_1 occurrence is the result of the onset of lactate production/utilization imbalance in the blood gathering from the involved contracting muscles among which some may produce lactate earlier than some others. On the other hand, EMG signals are a more direct reflection of the muscles involved. In other words, there is a possibility of detecting each individual muscle's EMG thresholds. This cannot be achieved when using a gas exchange method, which only reflects the averaged or overall metabolic consequences of all the muscles involved. Moreover, we showed in a previous study (Hug et al. 2003) that a EMG sign of neuromuscular fatigue occurred significantly before VT_1 suggesting that the activation of muscle metaboceptors (i.e. type III and IV muscular afferents) might make a major contribution to the mechanisms responsible for the ventilatory changes leading to VT_1.

In this present study, two EMG thresholds occurred simultaneously in muscles that were clearly different in their fibre type composition (there was no significant difference between the eight muscles in the occurrence of EMG_{Th1} and EMG_{Th2}). Thus, in accordance with Lucia et al. (1999), we may conclude that, in professional cyclists, changes in the pattern of motor unit recruitment are not affected by the muscle fibre type composition. Statistical analysis revealed no significant inter-muscle differences concerning the percentage of EMG threshold occurrence. However, as shown in Table 1, EMG_{Th1} was determined in 100% of the subjects for VL but only in 50% for GL. This lack of significance is likely due to the small sample of the tested population (i.e. eight professional road cyclists). The measurement of the EMG response in VL and BF permitted the determination of two EMG thresholds in 100% of the subjects. In agreement with the results of Jorge and Hull (1986), these muscles are some of those most highly involved in cycling. Moreover, Takaishi et al. (1998) showed a particular pedalling skill adopted by trained cyclists that required a high level of involvement of the BF muscle. This result might explain the high percentage of occurrence of the EMG thresholds in these two muscles.

Conclusion

In professional road cyclists, the EMG activities of eight lower limb muscles involved in pedalling showed two non-linear increases (i.e. EMG_{Th1} and EMG_{Th2}). The first EMG threshold preceded the first ventilatory threshold. Inversely, the second EMG and ventilatory thresholds occurred at the same percentage of power output.

These results suggest that the use of EMG may be a useful non-invasive method for detecting the second ventilatory threshold in most of the muscles involved in cycling exercise.

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