Are EMG patterns and activity levels modified at different points of the cycling torque-velocity relationship?

Sylvain Dorel, François Hug, Antoine Couturier and Gael Guilhem
EA 4334 “Motricité, Interactions, Performance” UFR STAPS, Université de Nantes
Research Department, National Institute for Sports (INSEP), Paris

SUMMARY
The present study was designed to assess the muscle coordination (level and timing of muscle activity) during specific maximal cycling task performed at different points of the maximal torque-velocity relationship. Using a rigorous MVC normalization technique (CON-TREX ergometer), the RMS activity level and EMG pattern for 11 lower limb muscles were determined during five all-out cycling sprints performed in isokinetic mode (from 60% to 140% of the optimal pedaling rate: Vopt). This study provides evidence that EMG activity level is not systematically maximal for all muscles involved in the maximal pedaling task and especially for the thigh bi-articular muscles (BF, SM) and the mono-articular hip extensor (GMax). Furthermore, the modifications of EMG patterns observed with increased the pedaling rate highlight adjustments of the muscle coordination in this poly-articular cyclic movement, but fail to demonstrate significant changes in the EMG peak activity for each muscle.

INTRODUCTION
Theoretically, based on the maximal force-velocity relationship obtained on isolated muscle, the model assumes that the amplitude of neural excitation arriving at the muscle (represented by the EMG activity) should be always maximal notwithstanding the velocity condition. Nevertheless, from a biomechanical point of view, pedalling remains a complex multi-joint cyclic movement of the lower extremity that therefore requires specific coordination of the lower-limb muscles [3]. Several studies have reported the influences of constraints such as the pedaling rate, torque or power output on the EMG activity during cycling in submaximal conditions [3]. On the other hand, literature concerning the EMG activity and muscle coordination during maximal cycling exercise is scarce.

The few studies that have investigated the EMG activity during non isokinetic sprint cycling exercise showed a relative constant level of activity of the main lower limb muscles regardless the external force and velocity recorded [2,5]. Additionally, the second study pointed out an alteration of muscle coordination at high pedalling rates. However, in these two studies, only a few muscles were investigated (GMax and VL for Samozino et al., GMax, VL, RF, BF, GL for Hautier et al.). Moreover these previous works did not focus on the EMG activity level of each muscles involved in the cycling movement and failed to compare actually different constant velocity conditions. Therefore, the aim of the present study was first to estimate the level of activity of each muscle group that can be measured by surface EMG technique during the maximal isokinetic cycling exercise. A second purpose was to identify potential changes of the coordination (level of activity and/or EMG pattern) with changes in the torque-velocity condition.

METHODS
Seventeen elite sprint cyclists volunteered to participate in this study (6 women, 11 men; aged 22 ± 3 years; height 173 ± 8 cm; weight 76 ± 11 kg). During a first session, the participants were asked to perform a torque-velocity test (3 cycling sprints of 5-s with 8-min of total recovery) according to the protocol proposed by Dorel et al. [1]. During a second experiment, isometric maximal voluntary contractions (MVC, 3-s) in flexion (FLEX) and extension (EXT) for the three articulations of the lower limb: hip (45° in EXT, 60° in FLEX), knee (70° in EXT, 50° in FLEX) and ankle (0° in EXT -10° in FLEX) were performed on an isokinetic CON-TREX ergometer (CMV AG Con-Trex, Switzerland). Then, after a classical cycling warm-up, subjects performed five maximal cycling exercises (5-s) in an isokinetic mode at different pedaling rates (randomized order) corresponding to 60%, 80%, 100%, 120% and 140% of their optimal pedaling rate (Vopt: pedaling rate at Pmax).

Surface EMG activity was continuously recorded during MVC and cycling sprints for eleven muscles: gluteus maximus (GMax), semimembranosus (SM), long head of biceps femoris (BF), tensor fasciae latae (TF), vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), gastrocnemius medialis (GM) and lateralis (GL), soleus (SOL) and tibialis anterior (TA). Pairs of surface electrodes were attached to the skin and were located according to the recommendations of SENIAM. Raw EMG signals were amplified, digitized at a sampling rate of 1 kHz (ME6000P16, Mega Electronics Ltd®, Finland), high-pass filtered (20 Hz, Butterworth filter), RMS and finally smoothed (zero lag low-pass filtered adapted to the pedaling rate: 18 Hz for 60%Vopt, to 42 Hz for 140%Vopt).

Maximal level of activity RMSmax for each muscle was calculated over a period of 200 ms of the corresponding MVC. EMG pattern was drawn by averaging 5 consecutive cycles. The maximal value during the burst (RMSpeak) and the mean value throughout the cycle (RMScycle) were determined and used for the comparisons between the velocity conditions. Changes in EMG variables with the pedaling rate were tested using an analysis of variance for repeated measures. Modification in timing of EMG patterns mentioned in results section was assessed using the cross-correlation technique (detailed results are not presented).

RESULTS AND DISCUSSION
For each muscle, $RMS_{peak}$ and $RMS_{cycle}$ expressed in percentage of $RMS_{isomax}$ are depicted in Figure 1. The ANOVA demonstrated significant effects of pedaling rate for $RMS_{cycle}$: a decrease with pedaling rate for knee flexors and/or plantar flexors and/or hip extensors (SOL, GM, GL, BF, SM and GMax), an absence of modification for mono- articular knee extensors (VL, VM) and dorsi flexors (TA) and/or plantar flexors and/or hip extensors (SOL, GM, GL, GMax), an increase for hip flexors (RF and TF). As a whole, these results are not clearly accompanied by modifications of $RMS_{peak}$ (except for GMax, TA and to a lesser extent to BF) suggesting an influence of pedaling rate on the EMG activity repartition among the complete cycle rather than a modification of the maximal level of activity of the muscles. These findings are supported by the analysis of EMG patterns which showed particular adjustments: some leg and thigh muscles (GL, GM, BF, SM, GMax) were recruited during a longer time period across the crank cycle at the lower pedalling rate compared to the higher (Figure 2). These adaptations probably reflect a strategy to enhance the net mechanical production during the downstroke (GMax), and the propulsive knee flexion action in the bottom dead center and the upstroke (GL, GM, BF, SM).

Consistent with the literature [4], an earlier activation of all the thigh muscles was found as the pedaling rate increased. However, as already reported [5], this compensatory strategy due to the constant electromechanical delay was certainly not sufficient to fully prevent the forward shift of the force production especially because of the lack of modification (SOL, TA) or the slight later activation (GL and GM) observed for leg muscles as pedaling rate increased. In fact, these opposite changes in the timing of leg muscles compared to thigh muscles could be responsible to a non optimal transfer of the power produced by the knee and hip extensors to the crank.

Regardless changes of coordination induced by alteration in the movement velocity, important findings are that i) the absolute level of activity appeared to be relatively different between muscle groups and ii) an significant inter-individual variability was observed. Despite the typical limitations inherent to MVC normalization technique (which are substantially reduced regarding the MVC protocol and the population), it was showed that $RMS_{peak}$ was not constantly maximal across the muscle groups. Indeed, it ranged between maximal (90-110% for GM, GL and SOL), quasi maximal (80-90% for VM, VL, RF, TF) and sub maximal level (60-80% for TA, BF, SM, GMax).

**CONCLUSIONS**

Different torque-pedaling rate constraints induced both significant quantitative and qualitative adjustments of the muscle coordination during maximal cycling. The present study provides evidence of non maximal level of activity (i.e. < 70% $RMS_{isomax}$) for some lower limb muscles involved in the maximal pedaling exercise; especially the thigh bi-articular muscles (BF, SM) and the mono-articular hip extensor (GMax). Overall, these results highlight the complexity of the coordination during this poly-particular movement but also put forward the debatable issue: how reasonably to use this maximal task as a reference normalization condition for all the lower limb muscles?

**REFERENCES**


**Figure 1:** Maximal ($RMS_{peak}$) and mean RMS values over the complete crank cycle ($RMS_{cycle}$) in five torque-pedaling rate conditions during maximal cycling exercise and for 11 lower limb muscles. Isokinetic conditions: from 60%Vo(60%: almost 60-70 rpm) to 140%Vo(140%: almost 170 to 190 rpm).

**Figure 2:** Mean RMS EMG envelopes for 4 of the 11 lower limb muscles during cycling sprints at low (60%Vo, grey line), intermediate (100%Vo, black line) and high (140%Vo, dotted lines) pedalling rates.