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SHORT COMMUNICATION

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Muscular activity level during pedalling is not affected by crank inertial load

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Abstract The aim of the present study was to investigate the influence of gear ratio (GR) and thus crank inertial load (CIL), on the activity levels of lower limb muscles. Twelve competitive cyclists performed three randomised trials with their own bicycle equipped with a SRM crankset and mounted on an Axiom ergometer. The power output (~80% of maximal aerobic power) and the pedalling cadence were kept constant for each subject across all trials but three different GR (low, medium and high) were indirectly obtained for each trial by altering the electromagnetic brake of the ergometer. The low, medium and high GR (mean ± SD) resulted in CIL of 44 ± 3.7, 84 ± 6.5 and 152 ± 17.9 kg·m^2, respectively. Muscular activity levels of the gluteus maximus (GM), the vastus medialis (VM), the vastus lateralis (VL), the rectus femoris (RF), the medial hamstrings (MHAM), the gastrocnemius (GAS) and the soleus (SOL) muscles were quantified and analysed by mean root mean square ($\mathrm{RMS}_{\mathrm{mean}}$). The muscular activity levels of the measured lower limb muscles were not significantly affected when the CIL was increased approximately four fold. This suggests that muscular activity levels measured on different cycling ergometers (with different GR and flywheel inertia) can be compared among each other, as they are not influenced by CIL.

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Introduction

In the sport and exercise sciences, cycling is a common form of exercise for general and cycling science investigations performed in the laboratory and the field. Different classical stationary ergometers (e.g., Axiom, Monark, Lode, Kingcycle,) and mobile powermeters (e.g., SRM, PowerTap, Polar S710, Ergomo), with different gear ratio (GR = number of teeth in the chain wheel/number of teeth in the freewheel), are being used in laboratory and field researches. This means that the crank inertial load (CIL) of studies involving cycling exercise also largely varies, as CIL is known to be affected by the used GR of the bicycle/ergometer and the weight of the ergometer flywheel (Fregly et al. 2000).

In order to gain an insight into the interaction between the motor control system and cycling, it is of interest to study the influence of CIL on the muscular activity level during pedalling by comparing various laboratory and field cycling conditions (with different GR and inertia).

A recent study of Hansen et al. (2002) showed that the CIL affects the freely chosen pedal rate during cycling. The pedal rate increased with high compared with low CIL, possibly to compensate for the higher peak crank torque. These higher peak crank torques were also reported by Fregly et al. (1996), although they concluded that CIL has little effect on steady-state pedalling coordination because the net joint torques except the ankle plantar flexion produced by muscles were unaffected by CIL. However, they were unable to conclude decisively that activation of individual muscles is unaltered with CIL, i.e. the muscles forces could change with high CIL even though the net muscle joint torques do not (Fregly et al. 1996). Moreover, their subjects were recreational cyclists who were instructed to pedal smoothly (i.e., constant speed within a cycle). It is unclear if competitive cyclists without such pedal instructions would have led to the same results.

Thus, the aim of the present study was to examine whether the GR, and therefore, the CIL, affects the muscular activity level of the lower limb muscles at a high constant workload and pedalling cadence (CAD). We hypothesised that the muscular activity level would decrease at high CIL since it has been shown by Fregly et al. (1996) that (1) the peak-to-peak variation in crank angular acceleration within the cycle and (2) the variation in CAD should be lower, due to diminished sensitivity to slight variations in the crank torque. Both changes would subsequently modify the kinetics of pedalling and thus the muscular activity level.

Methods

Subjects

Twelve well-trained male competitive cyclists of the French Cycling Federation volunteered to participate to this study. The Subject's height and mass mean ±(SD) age, were: 28 ± 8 years, 178 ± 4.5 cm, and 70 ± 4.3 kg, respectively. Before participating, the subjects were given verbal and written explanation of the purpose and the procedures of the study, and informed consents were obtained. All the subjects had regularly trained for cycling for at least 2 years prior to the study.

Experimental design

Each subject performed two test sessions in a climate-controlled laboratory (21.2–24.4°C, 41–52% relative humidity) with its own racing bicycle equipped with a power measuring crankset (SRM, Schoberer Rad Messtechnik, Weldorf, Germany) and mounted on a stationary electromagnetically brake ergometer (Axiom PowerTrain, Elite, Fontaniva, Italy). The first test session was an incremental test to exhaustion to determine maximal aerobic power (MAP), maximal oxygen consumption ($VO_{2\mathrm{max}}$) and maximal heart rate ($\mathrm{HR}_{\mathrm{max}}$). The second test session consisted of three different randomised trials with three different GR and CIL. The power output (PO) and the CAD were kept constant during all the trials. Both test sessions were held within a period of 1 week and separated by at least 2 days. During all the tests, the subjects were cooled by an electric fan.

Material

The Axiom PowerTrain ergometer was used for both the tests and has recently been described by Bertucci et al. (2005). The bicycle tire pressure was inflated to 700 kPa. The bicycle was fitted with an eight strain-gauges SRM crankset (the scientifique model) and subjects used their own clipless pedals and cycling shoes. The SRM crank set allowed measurement of PO, CAD and HR. The validity of PO recorded using a SRM crankset has been assessed by Martin et al. (1998). Before each test, the zero power offset of the SRM crankset was reset according to the manufacturer's recommendations which have been previously described in detail by Jones and Passfield (1998).

A CPX breath-by-breath gas analyser (Medical Graphics, St. Paul, USA) and a chest belt (Polar Electro, Kempele, Finland) were used during the first test session to collect the metabolic and HR data. The CPX system was calibrated before every test according to the manufacturer's recommendations.

The muscular activity levels of the gluteus maximus (GM), the vastus medialis (VM), the vastus lateralis (VL), the rectus femoris (RF), the long head of biceps femoris (BF), the medial hamstrings (MHAM, i.e., the semimembranosus and the semitendinosus), the medial gastrocnemius (GAS) and the soleus (SOL) of the right lower limb were monitored with surface electromyography (EMG) during the second session. The EMG sensors and the sensors placement were conformed to the recommendations of the European concerted action of Surface EMG for a non-invasive assessment of muscles, i.e., the SENIAM (Hermens et al. 2000). Sites were shaved and cleaned with alcohol swab in order to reduce skin impedance to less than 15 kΩ, which is in line with the recommendation of Hewson et al. (2003). Pairs of silver/silver-chloride circular bipolar pre-gelled surface electrodes (Control Graphique Medical, Brie-Comte Robert, France) of 20 mm diameter, with a centre to centre distance of 30 mm, were applied along the muscle fibre between the distal motor endplate zone and the distal tendon of the eight muscles for EMG data acquisition. The reference electrodes were placed over electrically neutral sites (vertebras). All the electrodes were fixed on the skin with adhesive pads and wires between the electrodes and the amplifier were secured to the skin with adhesive tape to prevent movement artifact. The EMG signals were amplified (Biopac MP30, Biopac Systems, Inc., Santa Barbara, USA) with a bandwidth frequency ranging from 50–500 Hz (common mode rejection ratio >90 dB, input resistance = 1,000 MΩ, gain = 25,000) and digitised on-line (sampling frequency 1,000 Hz).

First test session

Briefly, the incremental test consisted of a 2 min warm-up at 130 W, followed by 30 W increments each 2 min until the subject became exhausted. This protocol has been described in detail by Bertucci et al. (2005). The CAD was kept at 90 rpm throughout the test. The MAP was defined as the PO maintained during the last completed workload stage.

Second test session

After a brief self-selected warm up period (less than 10 min), each subject performed three trials with three different GR and CIL, which were obtained indirectly by altering the Axiom electromagnetic brake. The three different electromagnetic brake conditions (low, medium and high) were randomised for each subject and the three obtained GR were termed HGR, MGR and LGR (for respectively high, medium and low). The PO (~80% MAP) was kept constant for all trials. Since the absolute PO differed between the subjects, these same brake forces for each subject resulted in slight differences in used GR and CAD between each subject. Nevertheless, although the CAD differed between subjects for each condition, each subject kept the same CAD across the three conditions. For each trial, the subjects cycled for approximately 2 min to establish a steady state pedalling pattern, after which EMG data were collected for ten consecutive crank cycles. Trials were separated by 3 min of passive recovery. Subjects had to maintain the same body position (seated with hands on the brake hoods or hands on the top of the handlebars) during the three trials in order to minimise biomechanical changes due to differences in posture.

Data analysis

The CAD and the PO were measured and stored every 1 s by the SRM crankset throughout each trial of the experimental session. CIL for each GR condition was calculated using the model of Fregly et al. (2000):

$$\mathrm{CIL}(\mathrm{kg\,m^2}) = I\left[\left(\frac{R_\mathrm{F}}{R_\mathrm{G}} \times \frac{R_\mathrm{D}}{R_\mathrm{R}}\right)^2\right]$$

where I is the rotational inertia of the Axiom flywheel (0.05 kg m^2), R_F is the number of teeth in the chain wheel, R_G is the number of teeth in the freewheel, R_R is the radius of the roller (0.02 m) and R_D is the radius of the wheel (0.34 m).

The raw EMG were expressed in root mean square (RMS) with a time averaging period of 20 ms. For each subject and for each individual muscle, the muscular activity level corresponded to the mean RMS for ten consecutive crank cycles. This method had ever been used during previous studies (Hug et al. 2004; MacIntosh et al. 2000; Sarre et al. 2003). The muscular activity levels of each trial were normalised to the maximal RMS value (peak EMG) measured during all the trials.

Statistical analysis

Statistical analyses were performed with Sigma Stat 2.03 (SPSS, Chicago, USA). The coefficients of variation of the RMS (CV = standard deviation/mean * 100) were determined for each muscle and for each GR condition. We considered that the muscle recruitment pattern was "common" between the subjects when the CV was less than 12%, as it was reported by Hug et al. (2004).

A Kruskall–Wallis non-parametric test was used to test for differences in muscular activity levels between the three conditions (HGR, MGR and LGR). When P was significant, post hoc multiple comparisons using Tukey test was conducted to determine the significant differences between the conditions. For all analysis, the statistical significance level was set at $p < 0.05$. All data are expressed as means ± SD in tables and figures.

Results

During the incremental test, the MAP was 366 ± 16 W, the $V\mathrm{O}_{2\max}$ was 70 ± 5 ml·min^{-1}·kg^{-1} and the $\mathrm{HR}_{\max}$ was 185 ± 10 bpm. This last result indicates that the subjects reached their $V\mathrm{O}_{2\max}$ since the $\mathrm{HR}_{\max}$ of the incremental test was not different compared with the $\mathrm{HR}_{\max}$ measured in field competitions. Mean (± SD) of GR, CIL, PO and CAD are presented for experimental test session in Table 1. The PO sustained by the subjects during the three trials were 81 (4.0), 80 (4.3) and 81 (4.2) % of the MAP, respectively, for the LGR, MGR and HGR conditions.

We reported in Table 2, the CV of the rms for each muscle and for each GR condition. The ranges of the CV were 8–34% for all conditions. Figure 1 shows the muscular activity levels of each muscle for the three GR conditions. The statistical analysis showed that there was no significant difference between the three conditions for all muscles.

Table 1 Gear ratio (GR), crank inertial load (CIL), power output (PO) and pedalling cadence (CAD) for the three GR conditions, when cycling at 80% MAP

Axiom brake force	High	Medium	Low
Condition	LGR	MGR	HGR
Gear	39×21–23	39×15–17	53×15–17
GR	1.7 ± 0.1	2.4 ± 0.1	3.3 ± 0.1
CIL (kg m^2)	44 ± 3.7	84 ± 6.5	152 ± 17.9
PO (W)	298 ± 12	293 ± 12	297 ± 14
CAD (rpm)	92 ± 3.5	92 ± 3.2	92 ± 3.3

Table 2 Mean RMS coefficient of variation (%) across the three GR conditions for the gluteus maximus (GM), the rectus femoris (RF), the vastus medialis (VM), the vastus lateralis (VL), the hamstrings (MHAM), the biceps femoris (BF), the gastrocnemius (GAS) and the soleus (SOL), when cycling at 80% MAP

	GM	RF	VM	VL	MHAM	BF	GAS	SOL
LGR	34	21	19	16	30	22	16	10
MGR	34	25	19	25	34	22	14	8
HGR	28	21	21	23	30	21	14	10

Discussion

The main result of this study is that the muscular activity levels of the GM, VM, VL, RF, MHAM, BF, GAS and SOL muscles of experienced cyclists were unaffected by changes of CIL, which varied between 44 and 152 kg·m^2, during steady-state pedalling on a Axiom ergometer at ~80% MAP and constant CAD (~90 rpm).

Fregly et al. (2000) reported that CIL differs between different cycling conditions (i.e., ergometers and/or GR). To illustrate, CIL of road cycling varies widely from 23.5 to 167.1 kg·m^2 between the lowest (42×28) and the highest (52×13) GR, but much lower when cycling on rollers and a Velodyne trainer (between 2.0 and 13.9 kg·m^2 and between 16.0 and 113.7 kg·m^2, respectively). Moreover, the GR of a Monark ergometer is fixed at 52×14 and results in a CIL of 5.2 kg·m^2. According to this, Fregly et al. (2000) state that many cycling ergometer experiments correspond to road cycling in an extremely low GR against an extremely high head wind, due to the low CIL of the ergometers used. However, our study clearly indicates that cycling conditions with different CIL (which are obtained with different GR on a Axiom ergometer) do not differ in muscular activity levels of eight lower limb muscles. This suggests that: (1) study results concerning muscular activities measured on different cycling ergometers (with different CIL) can be compared among each other and (2) could even be compared to road cycling conditions despite the low CIL of some ergometers (e.g., Monark). Nevertheless, although CIL does not seem to affect muscular activity levels during cycling, it does affect freely chosen pedal rate (Hansen et al. 2002). Thus, it is still important to account for CIL when investigating cycling performance.

Our results are in agreement with the study of Fregly et al. (1996) that examined the effect of the CIL on the pedalling coordination. Nevertheless, Fregly et al. (1996) found that the ankle joint torque exhibited little statistical changes when the CIL was increased twenty fold. As the present study shows that the muscular activity levels of the GAS and the SOL were unaltered by an increase of CIL (Fig. 1), the alterations of the net ankle joint torque observed by Fregly et al. (1996) cannot be explained by an increase of the plantarflexor joint torque. However, it is possible that the muscular activity level of the tibialis anterior (TA), which is an antagonist of the GAS and SOL, and consequently the dorsiflexor joint torque, were decreased. Since we have not measured the muscular activity level of the TA, we can not discuss this potential contribution on the changes of the net ankle joint torque.

When regarding our results, three things need to be considered. At first, the muscular activity level variation among subject (CVs) was important, ranging from 8 to 34% and clearly indicating the inter-subject variability. Whatever the muscle, the CVs were very similar between the three GR conditions, indicating that the CIL had no effect of the inter-subject variability. Hug et al. (2004) have recently found similar variability in professional cyclists during incremental and constant exercises. According to these authors, it appears that only the recruitment pattern of the SOL is "common" between our subjects since its CV is lower than 10% for the three GR conditions. So, each competitive cyclist seems to use a pedalling strategy (level muscular activation) that is unique and could be related to their speciality during races (climbers, sprinters or time-trial specialists). This variability of the pedalling strategies (i.e., muscular recruitment) could have consequently masked the potential effect of the CIL on the muscular activation.

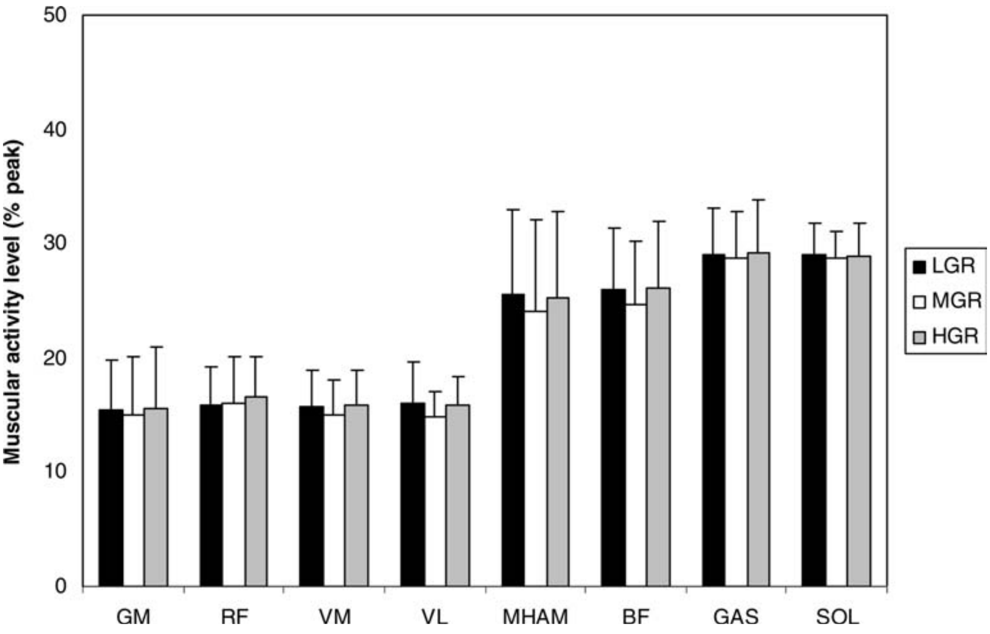

Fig. 1 Muscular activity level (mean RMS for ten consecutives crank cycles) of the gluteus maximus (GM), the rectus femoris (RF), the vastus medialis (VM), the vastus lateralis (VL), the hamstrings (MHAM), the biceps femoris (BF), the gastrocnemius (GAS) and the soleus (SOL) for the LGR, MGR and HGR conditions, when cycling at 80% MAP. The muscular activity levels are normalised to the maximal value measured during all the trials

However, this effect seems to be limited since the muscular activity level variation among subjects (CVs) are nearly similar between the three CIL condition (Table 1).

Secondly, the method used to evaluate muscle activation is debatable since RMS was averaged over the complete crank cycle, and thus include activation and relaxations phases. This could have hidden the differences between CIL conditions. In future studies, it would be interesting to analyse the effect of CIL on the timing of muscular activity (onset, offset and duration of activation).

Thirdly, as Fregly et al. (1996) have reported that (1) the peak-to-peak variation in crank angular acceleration and (2) the variation of the CAD should be lower at high CIL, and because we have not observed a significant decrease of muscular activity levels, it might be possible that the sensitivity of the surface EMG technology is not high enough to detect fine adjustments of muscular activity level, which are triggered by changes of CIL.

In conclusion, the results of the present study show that in experienced cyclists the muscular activity levels of the lower limb were not significantly influenced by the GR and thus by the CIL (range: 44–152 $\text{kg}\cdot\text{m}^2$) when cycling on a Axiom ergometer at 80% of their MAP and at constant CAD (~90 rpm). This means that despite the different CIL of various ergometers, the study results concerning muscular activities measured on different cycling ergometers can be compared among each other and could even be transferred to road cycling conditions. Further research on the relationship between CIL and the muscular activity levels should focus on (1) the initiation of pedalling, i.e., when the crank is accelerated or decelerated because much force and mechanical energy must be developed by muscles to accelerate a higher inertia for the same distance in the same amount of time, (2) the timing of the neuromuscular activity during steady-state pedalling and (3) higher CIL ($>160\ \text{kg}\cdot\text{m}^2$) that are encountered during level ground or downhill road cycling at high speeds.

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