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AN INVERSE DYNAMIC STUDY SUGGESTS THAT CYCLISTS MARGINALLY USE HIP JOINT TORQUE AT MAXIMAL POWER

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SUMMARY
This study aims to calculate net joint torques at ankle, knee and hip, using inverse dynamic during a maximal power cycling task on a cycle ergometer. These torques were then compared to maximum joint torques developed by each isolated articulation on isokinetic ergometer. Results show that subjects develop a maximal power (594±100W) during cycling at a pedaling frequency of 108±9RPM and an average torque at crank axis of 53.1±10Nm. Analyzing each joint torque reveals the leading part of the knee during the cycling task. Moreover, matching data from the isokinetic ergometer and from the cycling task, muscle force of hip extensors appears underused because only 33% of its maximal isometric torque is developed on the cycle ergometer.

INTRODUCTION
The inverse dynamic methods have been used in cycling tasks for a better understanding of geometric settings influence on the muscular torque developed at each joint of the lower limb. For some authors [1, 2], minimization of muscular torques is an important criterion of performance. Modifications of joint torques with standing mode, saddle height and power output level have already been analyzed [3, 4, 5, 6]. However, no comparison exists between torques developed by each joints during cycling and maximum capacity at these joints measured on isokinetic ergometer.

METHODS
Nine triathletes participated in this study. They were 32±10 years old, the mean height and body mass were 1.74±0.06m, and 64.6±6.8kg, respectively. They practice yearly 3100±1700km cycling since 11.7±10.9 years. The study consisted in two sessions spaced out of seven days.

The first test aimed to determine maximal power during cycling and associated nets joints torques at ankle, knee and hip. Usual settings of subjects were reproduced on the cycle ergometer in this sequence. A cycle ergometer Lode Excalibur with a crank length of 0,17m has been used. Subjects had to perform a protocol adapted from Vandewalle et al [7] consisting in six maximum pedaling phases of seven seconds against loads applied in random order with five minutes of passive rest between each. For each trial at maximal power, kinematics of lower limbs were analyzed using an optoelectronic Vicon system including ten cameras. Following ISB recommendations [8], three spherical markers were placed on anatomical landmarks corresponding to the hip, knee and ankle. Two additional markers were set up to identify cycle ergometer position. The cycle ergometer was instrumented with two pedals I-Crankset from Sensix to determine forces and torques applied by the foot on the crank. The acquisition frequency was set to 200Hz and the complete rotation of the cranks corresponding to the maximum power output was analyzed. Whole data have been filtered using a 4^{th} order butterworth low pass filter with a cut off frequency of 6Hz for kinematic and 10Hz for forces and torques. Mixing anthropometric data from de Leva et al. [9], kinematic from Vicon, forces and torques data from instrumented pedals, inverse dynamic was used to calculate net joint torques at ankle, knee and hip using Newton-Euler formalism applied at the feet, the leg and the thigh. This study has been realized in the sagittal plane and torques were determined around transverse axis.

The second test consisted in a measure of maximum torque performed on isokinetic ergometer Biodex. Maximum joint torques were determined at ankle, knee and hip in flexion and extension with concentric contractions. Maximum torques were measured for the whole range of motion of each joint at a rotation speed of 20°/sec. This slow speed was chosen to approach isometric conditions. For each subject, joints have been tested in a random order. A four minutes rest period was allowed between each joint test.

Each result is presented as mean ± standard deviation. A two ways analysis of variance ($P<0.05$) has been conducted to discern the difference at measured joints during the cycling and ergometer tests.

RESULTS AND DISCUSSION
For the cycling test, results give torque evolution along a rotation at the crank axis (figure 1), the hip (figure 2), the knee (figure 3) and the ankle (figure 4). The calculated torque at the crank axis is the result of the contribution of the two lower limbs while torque at each joint is the torque for one leg.

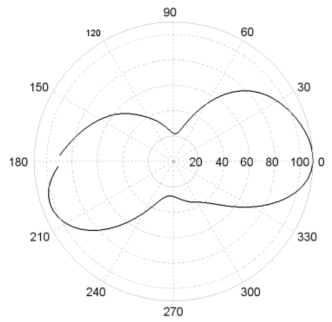

Figure 1 : Polar representation of the torque at crank axis

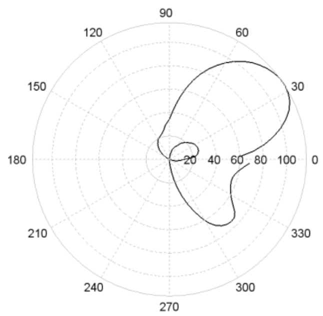

Figure 2: Polar representation of the torque at the hip

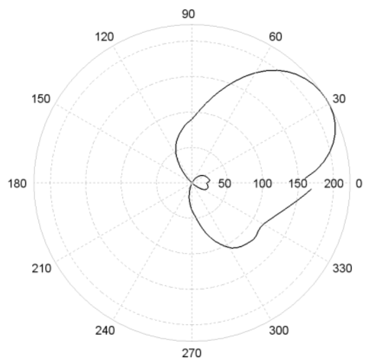

Figure 3: Polar representation of the torque at the knee

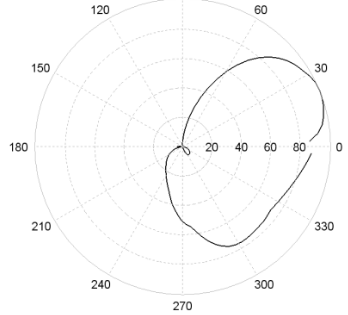

Figure 4 : Polar representation of the torque at the ankle

For this experience, subjects developed a maximal power of 594±100W at a 108±9RPM cadence and a mean torque of 53.1±10Nm at crank axis. For each joint, maximum torque is developed during the descent of the crank while joints are in concentric extension phase. During the rise of the crank, joints show a concentric flexion phase, meaning that subjects pull the clipless pedals during upstroke. When normalized to body mass, the maximum extension torque at the ankle is 1.14±0.27Nm/kg in extension and 0.18±0.09Nm/kg in flexion. At the knee, the maximum torque is 2.89±0.70Nm/kg in extension and 0.67±0.28N/kg in flexion. At the hip, it reaches 1.48±0.45Nm/kg in extension and 0.50±0.14Nm/kg in flexion. So, the knee develops torque value twice as large as those measured at the hip and at the ankle in extension. In flexion, peak torque at the knee and the hip is equivalent whereas it's rather low at the ankle.

Moreover, the comparison between maximum torques measured at each joint during cycling exercise and maximum torques measured on the ergometer reveals that hip is underused during maximum power cycling exercise. Indeed the ratio is by 33% of the isometric maximum torque reaches in extension during cycling, while ankle and knee are forced with respective ratios of 128% and 102%. In contrast, flexion capacity of each joint is rarely used with a mean ratio of 40%.

This shows that the cycling performance may be improved by better use of human capabilities especially at the hip and during flexion. However, this study is limited by speed movement which is approximately 500°/sec during cycling and only 20°/sec on ergometer, and according to Taylor et al. [10], higher speed results in a lower muscular torque. This outcome is not observed here particularly for ankle and knee extension. Moreover, bi-articular muscles can be extensor at one joint and flexor at another one. It can restrict maximum joint torques developed at the different level during overall movement like push-pull during cycling.

CONCLUSIONS

Finally, this study enables us to estimate net torque at each joint during maximal power exercise on cycling ergometer. Results show that triathletes well use ankle and knee during extension, while hip extension and flexion may be increased regarding the low solicitation level observed. A new way of pedaling thus remains to invent for a better utilization of each joint. New chainring and crankset types are perhaps future solutions to enhance the performance.

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