Journal of Human Kinetics volume 50/2016, 5-14 DOI: 10.1515/hukin-2015-0136
Section I – Kinesiology

DE GRUYTER
OPEN

Transferability between Isolated Joint Torques and a Maximum Polyarticular Task: A Preliminary Study

by
Antony Costes[1], David Villeger[1], Pierre Moretto[1,2,3], Bruno Watier[1,4]

The aims of this study were to determine if isolated maximum joint torques and joint torques during a maximum polyarticular task (i.e. cycling at maximum power) are correlated despite joint angle and velocity discrepancies, and to assess if an isolated joint-specific torque production capability at slow angular velocity is related to cycling power. Nine cyclists completed two different evaluations of their lower limb maximum joint torques. Maximum Isolated Torques were assessed on isolated joint movements using an isokinetic ergometer and Maximum Pedalling Torques were calculated at the ankle, knee and hip for flexion and extension by inverse dynamics during cycling at maximum power. A correlation analysis was made between Maximum Isolated Torques and respective Maximum Pedalling Torques [3 joints x (flexion + extension)], showing no significant relationship. Only one significant relationship was found between cycling maximum power and knee extension Maximum Isolated Torque (r=0.68, p<0.05). Lack of correlations between isolated joint torques measured at slow angular velocity and the same joint torques involved in a polyarticular task shows that transfers between both are not direct due to differences in joint angular velocities and in mono-articular versus poly articular joint torque production capabilities. However, this study confirms that maximum power in cycling is correlated with slow angular velocity mono-articular maximum knee extension torque.

Key words: *cycling, isokinetic ergometer, inverse dynamics, force-velocity test.*

Introduction

Joint torque is a common measure for researchers and practitioners in strength and conditioning biomechanics to evaluate performance. Joint torques can be evaluated by two methods, which include direct and isolated evaluations using isokinetic ergometers, classical conditioning devices (Baroni et al., 2013; González-Ravé et al., 2014), or by indirect and polyarticular methods combining kinetic and kinematic measurements, namely inverse dynamics (Hull and Jorge, 1985).

Given the widespread use of strength and conditioning in sports training and rehabilitation, isolated joint torques assessments are often used to monitor the athlete’s performance. This use has been questioned by Baker et al. (1994) who found no relationship between maximum isometric and dynamic force enhancements, and thus criticizing the use of isometric tests to monitor the athlete’s performance. In cycling, winning a race is often determined by the ability to produce high power output in order to create high velocities; a high crank power output is crucial to scale the athlete’s performance. To our knowledge, only one study in cycling examined the relationship between isolated joint torques and performance,

---

[1] - *PRISSMH, University of Toulouse, UPS, Toulouse, France.*
[2] - *University of Toulouse; UPS; Centre de Recherches sur la Cognition Animale; Toulouse Cedex 9, France.*
[3] - *CNRS; Centre de Recherches sur la Cognition Animale; Toulouse Cedex 9, France.*
[4] - *CNRS, LAAS, Toulouse, France.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 50/2016 in March 2016.

represented by the maximum crank power output (Driss et al., 2002). In this study, the authors assessed correlations between maximum cycling power and knee extension joint torque at different velocities ranging from 0°·s-1 (isometric mode for a single knee angle of 120°) to 240°·s-1. They found significant correlations between maximum cycling power and knee extension joint torque. However, isolated joint measurements performed in non ecological conditions may not represent the performance in polyarticular dynamic tasks like running, cycling or rowing because of factors like energy storage/releasing, difference in joint angular velocity, inter-segmental coordination, or differences in torque production capabilities between mono-articular and polyarticular testing (Hahn et al., 2011). Indeed, it is not known if these limits are strong enough to preclude correlations between isolated joint torques and the same joint's torques in a polyarticular task given the possible correlations between low and high angular velocity joint torque capabilities (Anderson et al., 2007). For practitioners, the main outcome of this comparison is to establish if a strength/weakness of an isolated joint is found in the same joint involved in a multi-joint task despite muscular and articular redundancy. If both are correlated, it would remain an ideal diagnostic tool to direct training, and if they are not, it would restrict the interest of isolated joint testing when the goal is to develop capabilities on a polyarticular task.

While a series of studies are required to compare isolated joint torques with joint torques in all maximum polyarticular tasks, this one aimed to be the first to make this comparison, and was designed to examine cycling due to the prevalent use of inverse dynamics in this activity (for review, see Bini and Diefenthaeler, 2009). Two objectives were set: (a) to determine if isolated maximum joint torques are correlated with the same joint's torque during cycling at maximum power despite joint angular velocity differences, and (b) to evaluate if an isolated maximum joint torque is correlated with cycling performance, and so add the five other joint movements (i.e. ankle, knee, and hip flexion and extension) to the knee extension torque tested by Driss et al. (2002).

Material and Methods

Participants

Nine cyclists (32 ± 10 years old, body height 1.74 ± 0.06 m, body mass 64.6 ± 6.8 kg, annual cycling practice 3100 ± 1700 km) volunteered for the study. The subjects can be considered as recreational cyclists (Category 4 in Ansley and Cangley (2009) classification). This population was chosen in order to get a broad range of maximum crank power production capabilities given the goal of assessing correlations using this variable.

Measures

Two experimental sessions were realized, one to evaluate Maximum Isolated Torques (MITs) and one to evaluate Maximum Pedaling Torques (MPTs). MITs and MPTs were assessed for ankle, knee, and hip flexions and extensions.

MITs of each joint were assessed at low velocity in random order on an isokinetic ergometer (BIODEX, Shirley NY, United States of America). Then, to assess MPTs, the subjects first conducted a cycling torque-velocity test on an instrumented Excalibur cycle ergometer (LODE, Groningen, Nederland) that consisted of six maximum velocity pedalling sequences against various loads proposed in random order (Vandewalle et al., 1987). The MPT represented their instantaneous maximum joint torques during the most powerful crank cycle of the test. A time delay of 7 ±2 days was adopted between MIT and MPT assessments.

Maximum Isolated Torque (MIT) measurement

MIT determination was preceded by a 10 min warm-up on a cycling ergometer at a freely chosen cadence (Power = 100 W). Measures of maximum flexion and extension torques were realized separately at the ankle (from 10° of dorsiflexion to 50° of plantarflexion), the knee (from 50° of flexion to 60° of extension) and the hip (from 40° flexion to 50° in extension) on an isokinetic ergometer (BIODEX, Shirley NY, United States of America). The measurements were randomized across joint movements to avoid learning or sequence effect. Each torque was assessed using an isokinetic angular velocity of 20°/s with a maximum range-of-motion allowing to overlap the one used by the joint when pedalling. Differences of maximum joint torque between the isometric condition and such a low velocity can be considered as not significant on six movements assessed (Anderson et al., 2007). but with the advantage to allow assessing a complete range-of-motion and minimizing fatigue in comparison to repeated isometric tests at different joint angles. Before each test, the rotation axis of the dynamometer was carefully aligned with the joint axis, using BIODEX recommendations of positioning for each joint. Two passive returns of the arm fixing the segment were done prior to each sequence in order to measure the torque due to the limb and the measurement tool weights. One sub-maximal trial of familiarization was first performed, and then the following one was selected for MIT evaluation. MIT for a given joint movement was the maximum torque value obtained during a full extension or flexion (i.e. one value for the optimal angle of the joint's range-of-motion). A rest period of 4 min was allowed between each unilateral joint movement test.

Determination of maximum cycling power

This session was separated by 7 ±2 days with regard to the MIT assessment. Subjects were placed on the ergometer according to their usual settings. The crank length was set at 0.17 m and the saddle height was adjusted if necessary to keep usual leg extension. The test began with an identical warm-up (10 min at 100 W, freely chosen cadence). Standardized instructions were given after the warming-up phase and no encouragement or feedback was provided. According to the classic recommendations for a torque-velocity test (Vandewalle et al., 1987), it consisted of six pedalling phases of 7 s at maximum velocity against loads presented in random order to avoid learning or sequence effect. Participants started each sprint with the load already applied and a horizontal and static crank position. Five minutes of passive rest were given between each sprint. The subjects were asked to pedal seated during the whole evaluation.

Maximum Pedalling Torques (MPT) evaluation

Kinematic data of the lower limbs were recorded in three dimensions at 200 Hz using an optoelectronic system composed of ten cameras (VICON, Oxford, United-Kingdom) located around the cyclist. Then, positions of the markers were projected in the sagittal plane of the cyclists. Three spherical reflective markers were placed on anatomical landmarks corresponding to the hip, knee and ankle joints, the great trochanter, the lateral femoral condyle and the lateral malleolus according to the International Society of Biomechanics (ISB) recommendations (Wu et al., 2002) adapted for a one-plane analysis. Two additional markers were placed on the heel and the toe for the foot to match the anthropometric model proposed by de Leva (1996). Two others markers were positioned on each side of the pedals to identify the position of the pedal spindle. Segments were considered rigid, with fixed centers of mass, fixed inertial parameters, and connected by frictionless joints. Figure 1 illustrates the theoretical model used to represent the cyclist.

Markers positions were filtered using a 4th order Butterworth low-pass filter with zero phase lag and a cutoff frequency of 6 Hz. The pedals were equipped with 3-dimensions force/torque sensors (I-Crankset-1, SENSIX, Poitiers, France), which recorded the applied reaction forces and moments at 1 kHz. Kinetics data were treated with a cutoff frequency of 10 Hz. Kinetics and kinematics were synchronized using the Nexus 1.7.1 system (VICON, Oxford, United-Kingdom).

A classic bottom-up inverse dynamics method (Hull and Jorge, 1985) written with Scilab 5.4.0 (SCILAB, Scilab Enterprises) was programmed to compute the MPTs in two dimensions during the crank cycle corresponding to the maximum power of the torque-velocity test. MPTs were selected as the maximum joint torques during the cycle corresponding to the maximum crank power.

Procedures

For the MIT, the data analyzed were the instantaneous maximum joints torques. MPT represented the instantaneous maximum torques for each of the six joints conditions [3 joints x (flexion + extension)] for each subject during the crank cycle corresponding to the maximum power output. A typical example of MPT and MIT processing according to crank power-velocity and crank torque-velocity relationships is presented in Figure 2. For both MPT and MIT, instantaneous values of torque were conserved. On the other hand, mean values of maximum cycling power during one cycle were retained given the involvement of each joint movement in this variable. Each participant was informed of the experimental procedure and signed an informed consent form before study initiation. The experimental design of the study was conducted in accordance with the declaration of Helsinki and approved by the ethical committee of the University of Toulouse.

Statistical Analysis

All statistical analyses were performed using STATISTICA (StatSoft, Maisons-Alfort, France). Data normality was assessed using the Shapiro-Wilk's test, and homogeneity of variance was verified using the Levene's test. Correlations between MIT and MPT and between MIT and maximum cycling power were performed using the Pearson R test with the level of significance set at $p < 0.05$. For descriptive purposes, MPT/MIT ratios were compared using a repeated measure ANOVA. Data are presented as mean ± standard deviation and the p value below 0.05 was considered significant.

Results

Maximum cycling power was of 594 ± 110 W which represents 9.2 ± 1.7 W/kg of body mass. The mean cadence for this cycle was 108 ± 9 RPM, and the mean crank torque was 53.1 ± 10 Nm (0.82 ± 0.15 Nm/kg of body mass). Values of MPT and MIT at the ankle, knee and hip joints are presented in Table 1.

No significant correlations were found between MPT and MIT. Pearson's r-values ranged from 0.06 to 0.59 (p > 0.05) (Table 2).

Maximum crank power was correlated with knee extension MIT (r = 0.68, p < 0.05). Maximum crank power was not correlated with any other MIT (r ranging from 0.09 to 0.45).

This analysis showed that the ratios between MPT and MIT were highest for the ankle and knee extension when compared to other movements (p < 0.05), with no difference between the two mentioned. There was also a significant difference between knee flexion and hip flexion (p < 0.05). No other significant differences were detected (Figure 3).

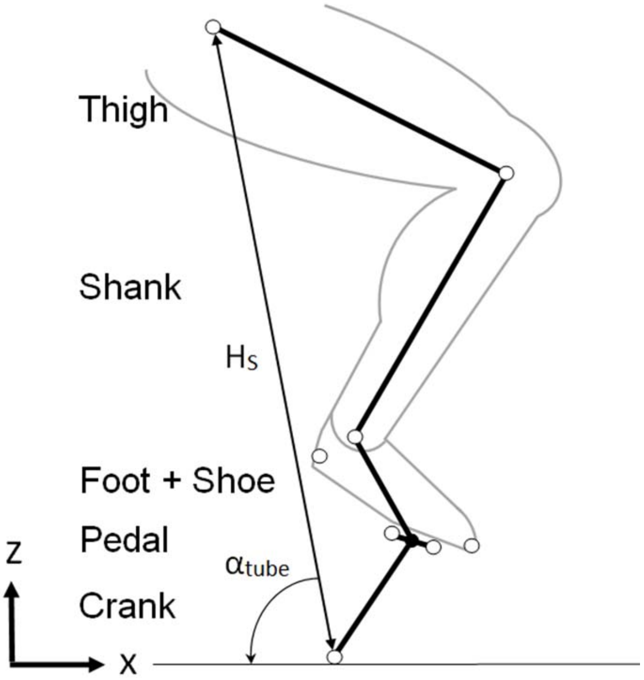

Figure 1

Theoretical model of the cyclist

α_{tube}: saddle tube angle. H_s: hip to crank axis length.

Each dot represents a reflective marker used for the kinematics analysis.

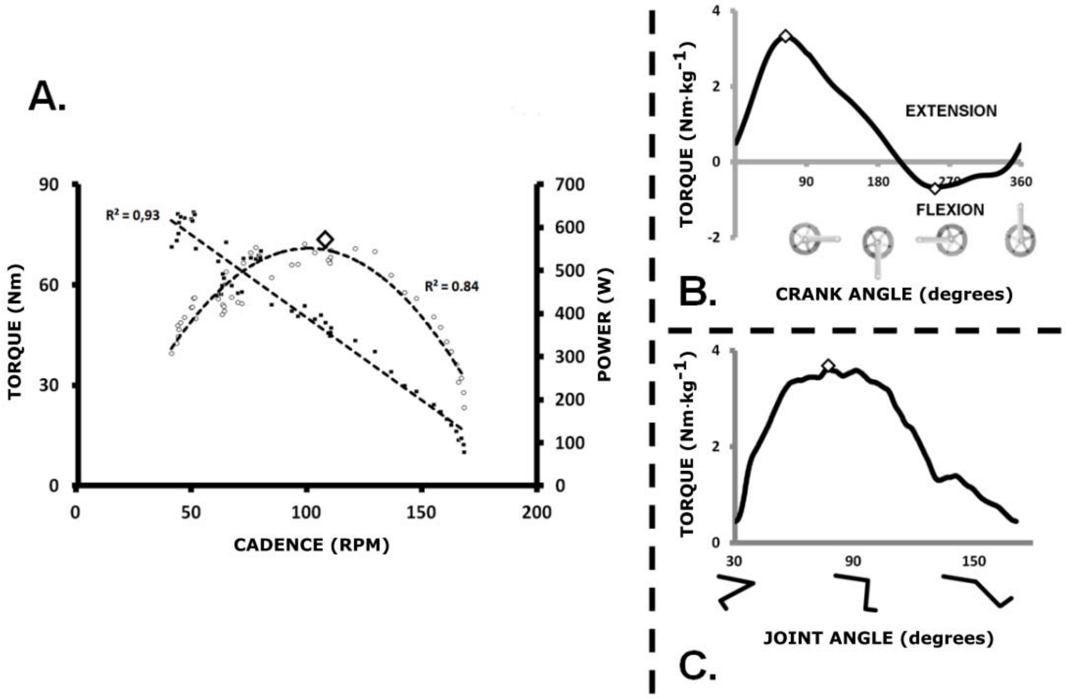

Figure 2

***Power-Cadence, Torque-Cadence and Torque-Angles relationships**.*
A. Power as a function of the cadence (2nd order polynomial curve) and crank torque as a function of the cadence (linear relationship) for one participant during the maximum power determination test. One dot represents the average torque (black squares) or average power (white circles) for a whole crank revolution of the torque-velocity test. Data represent the six sprints. The diamond at maximum power indicates the studied cycle to compute MPT of each joint movement. B. MPT assessment for the same subject detailing knee joint torque as a function of the crank angle. The two diamonds indicate instantaneous maximum knee extension and flexion torques (MPT for these two joint movements). This process was repeated for the ankle and hip joints. C. MIT assessment of knee extension for the same subject as a function of the knee angle. The diamond represents the instantaneous maximum knee extension torque (MIT for this movement). This assessment was repeated for knee flexion, as well as ankle and hip flexion and extension.

Table 1

Mean values and standard deviations of the mechanical parameters assessed during the experimental protocol

Joint	Ankle		Knee		Hip	
Movement	Flexion	Extension	Flexion	Extension	Flexion	Extension
MPT (Nm·kg^{-1})	0.18±0.09	1.14±0.27	0.67±0.28	2.89±0.70	0.50±0.14	1.48±0.45
Joint Angular Velocity at MPT (degrees·s^{-1})	170±78	148±99	317±97	324±69	106±119	167±42
MIT (Nm·kg^{-1})	0.44±0.07	0.89±0.33	1.41±0.53	2.84±0.72	1.68±0.48	4.52±1.07

MPT: Maximum Pedaling Torque (maximum torque during the maximum power output pedaling cycle), MIT: Maximum Isolated Torque (maximum torque over the joint range of motion at 20°/s).

TABLE 2

Correlations (r) between MPT and MIT and between maximum cycling power and MIT (= significant p < 0 .05).*

	Ankle		Knee		Hip	
	Flexion	Extension	Flexion	Extension	Flexion	Extension
MPT *vs* MIT	0.34	0.45	0.49	0.59	0.06	0.50
Maximum Cycling Power *vs* MIT	-0.09	0.45	0.41	**0.68***	0.42	0.43

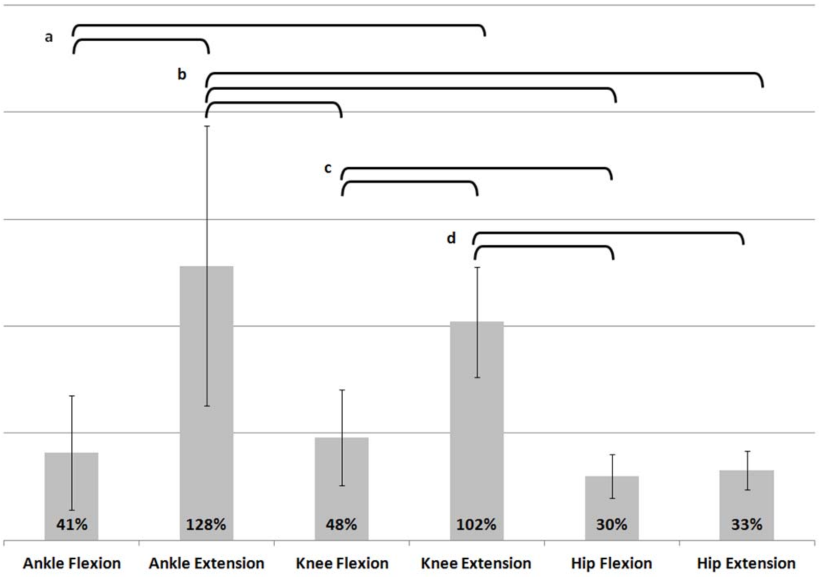

Figure 3

Ratios between Maximum Pedaling Torque (MPT) and Maximum Isolated Torque (MIT)

[a] Significant difference with Ankle Flexion, [b] Significant difference with Ankle Extension, [c] Significant difference with Knee Flexion, [d] Significant difference with Knee Extension.

Discussion

The first objective of this study was to verify if isolated measures of maximum joint torques using low velocity isokinetic testing similar to isometric conditions are correlated with torques on the same joints in a polyarticular task. Our data indicated that these correlations did not exist. This shows that the transfer between capabilities on isolated joints and the joint torques developed during a polyarticular task is not direct. A probable explanation for this result is the difference in joint angular velocity between MIT (20°·s-1) and MPT (see values for each joint in Table 1). This assumption was tested by Driss et al. (2002) who demonstrated that the correlation between maximum cycling power and isolated knee extension torque was better when using high joint velocities (i.e. 240°·s-1) during an isolated joint torque assessment (r=0.83 in their study) than when using isometric testing (r=0.54). Furthermore, another explanation for this lack of correlation may be the difference in joint torque development between isolated joints and a polyarticular joint action. In this sense, it has been shown that ankle torque production capability is higher when the ankle is involved in a polyarticular extension than in mono-articular testing (Hahn et al., 2011). Altogether, these results suggest that precautions are necessary in joint torque testing and conditioning in order to take into account the specificity of the task to develop in terms of joints involved and their angular velocities.

The second objective of our work was to determine if for the specific activity assessed, some isolated joint torque capabilities would be a better predictor of the athlete performance. This was the case for only one movement in the study with the knee extension maximum torque associated with better cycling power output. This finding is in line with the results of Driss et al. (2002) who demonstrated this correlation between maximum knee extension torque and maximum cycling power. However, lack of correlation for the other joint movements shown in this study gives more importance to the force development of muscles crossing the knee to improve cycling performance. The results regarding knee extension are in line with the findings of Elmer et al. (2011) and McDaniel et al. (2014) who described this joint movement as a large power generator during maximum cycling. The McDaniel et al.'s study also demonstrated the sensibility of joint power with regard to the crank angular velocity, showing that ankle plantar flexion power part in the total power production decreased with an increasing pedaling rate, whereas knee flexion and hip extension parts increased. In their study, hip joint power was presented as the main power generator whereas a relative low involvement of hip extension was found in our study (Figure 3). Nevertheless, this result is consistent with a recent study using electromyography of eleven muscles that compared ratios of peak activation between sprint pedalling and isolated isometric contractions (Dorel et al., 2012). Note that because of differences in the studied populations, non-linearity between EMG signals and joint torques (Caldwell and Li, 2000), and methodological aspects of the EMG normalization (Burden, 2010), precautions must be taken when comparing these results. Remarkably in their study, the soleus (ankle extensor) had a ratio of activation between sprint cycling and isometric contraction of 127%, the gastrocnemii medialis and lateralis (ankle extensors and knee flexors) of 101% and 99%, respectively, the tibialis anterior (ankle flexor) of 76%, the vastus lateralis and vastus medialis (knee extensors) of 104% and 92%, respectively, the rectus femoris (knee extensor and hip flexor) of 99%, the tensor fasciae latae (hip flexor) of 81%, the semitendinosus and semimembranosus (hip extensors and knee flexors) 71% and 60%, respectively, and the gluteus maximus (hip extensor) of 77%. Both results confirm the fact that flexion capabilities are sparsely used during maximum power cycling, and this is also the case for the hip extension whereas this joint exhibits the greatest possibilities of torque production. In contrast, polyarticular ankle and knee extension seem to be the most used joints during cycling at maximum power in regard to their isolated capabilities in pseudo-isometric conditions.

For descriptive purposes, ratios of joint torques used during cycling with isolated maximum (MIT) as reference were established (Figure 3). The observed MPT/MIT ratio of 128% for ankle extension was an unexpected result, meaning that the torque at this joint during a dynamic task at fast angular velocity exceeded the one during a pseudo-isometric condition. This result could be explained by the length variation of the biarticular muscle gastrocnemii between MIT and MPT, which may have lead to a difference in muscle/tendon force, and so in ankle extension torque (Hahn et al., 2011). During fast running at 6.5 m/s which probably involves a larger portion of "elastic" energy (Raasch and Zajac, 1999), even higher ankle extension torques were reported: 3.43 ± 0.49 Nm/kg of body mass (in our study 1.14 ± 0.27 Nm/kg MPT and 0.89 ± 0.33 Nm/kg MIT), which could have lead to an hypothetical ratio Maximum Running Torques on MIT around 385%. The interest to develop ankle extension torque capabilities has already been shown in cycling: a greater decrease in joint power production than in other joints (50% less power generated after 15 s of a 30 s maximum pedalling test, versus about 30% for other joint movements) was previously observed (Martin and Brown, 2009), and a lower contribution of the ankle extension torque at the end of a cycling test to exhaustion at constant power output was described (Bini et al., 2010).

To enhance the sensibility of our method and determine the task-specific muscular needs, an assessment of individual muscle forces is necessary. The method is still to be developed, but coupling inverse dynamics with electromyography (Raasch et al., 1997) or using supersonic shear imaging (Bouillard et al., 2013) could be applied to set references of in vivo muscle force and compare them during a polyarticular task.

To conclude, in order to improve the transferability of strength and conditioning to performance in polyarticular activities, practitioners and trainers should test force characteristics at appropriate angular velocity, and train the athletes in natural setting situations rather than choosing isolated and angular velocity different joint conditioning. However, if the relation between one isolated joint capability and performance in a specific activity is shown, then isolated conditioning of this joint may be justified. The results of this study confirm that this is the case for knee extension and cycling maximum power. As discussed with MPT/MIT ratios, improvement in cycling could also be achieved by strengthening the muscles involved in ankle extension (keeping in mind the need of a polyarticular extension to take into account the gastrocnemii characteristics) given their important involvement in maximum cycling in regard to their capabilities. The findings of this study indicate that transfers between isolated joint torques and the same joint torques involved in a polyarticular task are not direct.

Acknowledgements

The authors would like to thank the participants for their enthusiastic participation, together with Pr Pier-Giorgio Zanone for reviewing the manuscript.

References

Anderson DE, Madigan ML, Nussbaum MA. Maximum voluntary joint torque as a function of joint angle and angular velocity: Model development and application to the lower limb. *J. Biomech,* 2007; 40: 3105–3113

Ansley L, Cangley P. Determinants of "optimal" cadence during cycling. *Eur. J. Sport Sci,* 2009; 9: 61–85

Baker D, Wilson G, Carlyon B. Generality Versus Specificity - a Comparison of Dynamic and Isometric Measures of Strength and Speed-Strength. *Eur. J. Appl. Physiol,* 1994; 68: 350–355

Baroni BM, Rodrigues R, Franke RA., Geremia JM, Rassier DE, Vaz MA. Time Course of Neuromuscular Adaptations to Knee Extensor Eccentric Training. *Int. J. Sports Med,* 2013; 34: 904-911

Bini RR, Diefenthaeler F. Mechanical Work and Coordinative Pattern of Cycling: A Literature Review. *Kinesiology,* 2009; 41: 25–39

Bini RR, Diefenthaeler F, Mota CB. Fatigue effects on the coordinative pattern during cycling: Kinetics and kinematics evaluation. *J. Electromyogr. Kinesiol,* 2010; 20: 102–107

Bouillard K, Jubeau M, Nordez A, Hug F. Effect of vastus lateralis fatigue on load sharing between quadriceps femoris muscles during isometric knee extensions. *J. Neurophysiol,* 2013; 111: 768-776

Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *J. Electromyogr. Kinesiol,* 2010; 20: 1023–1035

Caldwell GE, Li L. How strongly is muscle activity associated with joint moments? *Motor Control,* 2000; 4: 53–59

Dorel S, Guilhem G, Couturier A, Hug F. Adjustment of Muscle Coordination during an All-Out Sprint Cycling Task. *Med. Sci. Sports Exerc,* 2012; 44: 2154–2164

Driss T, Vandewalle H, Le Chevalier JM, Monod H. Force-velocity relationship on a cycle ergometer and knee-extensor strength indices. *Can. J. Appl. Physiol,* 2002; 27: 250–262

Elmer SJ, Barratt PR, Korff T, Martin JC. Joint-Specific Power Production during Submaximal and Maximal Cycling. *Med. Sci. Sports Exerc,* 2011; 43: 1940–1947

González-Ravé JM, Juárez D, Rubio-Arias JA, Clemente-Suarez VJ, Martinez-Valencia MA, Abian-Vicen J. Isokinetic leg strength and power in elite handball players. *J. Hum. Kinet,* 2014; 41: 227–233

Hahn D, Olvermann M, Richtberg J, Seiberl W, Schwirtz A. Knee and ankle joint torque-angle relationships of multi-joint leg extension. *J. Biomech,* 2011; 44: 2059–2065

Hull ML, Jorge M. A method for biomechanical analysis of bicycle pedalling. *J. Biomech,* 1985; 18: 631–644

De Leva P. Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *J. Biomech,* 1996; 29: 1223–1230

Martin JC, Brown NAT. Joint-specific power production and fatigue during maximal cycling. *J. Biomech,* 2009; 42: 474–479

McDaniel J, Behjani NS, Elmer SJ, Brown NA, Martin JC. Joint-specific power-pedaling rate relationships during maximal cycling. *J. Appl. Biomech,* 2014; 30: 423–430

Raasch CC, Zajac FE. Locomotor Strategy for Pedaling: Muscle Groups and Biomechanical Functions. *J. Neurophysiol,* 1999; 82: 515–525

Raasch CC, Zajac FE, Ma B, Levine WS. Muscle coordination of maximum-speed pedaling. *J. Biomech,* 1997; 30: 595–602

Vandewalle H, Peres G, Heller J, Panel J, Monod H. Force-velocity relationship and maximal power on a cycle ergometer. *Eur. J. Appl. Physiol,* 1987; 56: 650–656

Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, Whittle M, D'Lima DD, Cristofolini L, Witte H, Schmid O, Stokes I. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *J. Biomech,* 2002; 35: 543–548

Corresponding author:

Antony Costes
PRISSMH, University of Toulouse, UPS, 118 route de Narbonne, 31062 Toulouse, France
Adress: Bureau 211, Pôle Sport, 118 route de Narbonne, 31062 Toulouse, France
Phone: +33 (0) 5 61 55 64 40;
Fax: +33 (0) 5 61 55 82 80
E-mail: address: antony.costes@univ-tlse3.fr