ORIGINAL RESEARCH PAPER

COMPARISON OF LOWER LIMB ISOKINETIC MUSCLE PERFORMANCE BETWEEN ROAD CYCLISTS AND MIDDLE DISTANCE RUNNERS

Indrek Rannama, Karin Baskin, Meeli Roosalu, Kristjan Port, Vladimir Kunitson

Tallinn University
Address: 55 Tondi Street, 11316 Tallinn, Estonia
Phone: +372 6996544
E-mail: rannama@tlu.ee

Abstract

The purpose of this study was to compare the isokinetic muscle performance of lower limbs in middle distance runners and road cyclists. Subjects: 10 competitive Estonian middle distance runners (age 23.8 ± 3.8 yrs., height 181.8 ± 2.8 cm, mass 73.6 ± 7.4kg) and 16 road cyclists (21.1 ± 3.5 yrs., 181.5 ± 5.0cm, 74.8 ± 7.0kg) volunteered in this study. Methods: Isokinetic strength of ankle plantar flexors (A-pf), ankle dorsal flexors (A-df), knee (K) and hip (H) extensors (ex) and flexors (fl) were measured with Humac NORM isokinetic dynamometer in angular speeds 60, 180 and 240 °/s. Isokinetic peak torque (PT), and power (P) values of best repetition and total work (ToW) of 15 repetitions in angular speed 240°/s were expressed as a mean of dominant and non-dominant leg. The absolute and relative isokinetic values were compared between runners and cyclists. Results: The comparison of PT values shows that cyclists have significantly (p<0.05) higher results in A-pf and K-fl in all testing speeds. No significant differences between A-df, K-ex, H-fl and H-ex PT values at any speed were found. Cyclists had also significantly higher P results in A-pf, K-fl and K-ex in all testing speeds and tendency (p=0.08) in H-ex 60°/s. ToW values of A-pf, K-ex and K-fl were significantly higher in cyclists group, but runners had higher values in H-fl. Conclusion: Cyclists have higher isokinetic muscle performance values in A-pf, K-fl, and K-ex and runners have higher total work ability in H-fl. No significant differences in A-df and H-ex performance between cyclists and runners were found. Runners and cyclists have also different power-velocity curves of A-df, H-ex, K-ex and K-fl

Keywords: *power, peak torque, isokinetic dynamometry.*

Introduction

Cycling and running are most common sports for development of endurance abilities. The differences in physiological adaptions between endurance cyclists and runners are well reported (Millet et al., 2009). Although endurance running and cycling places high demands on aerobic characteristics, runners also have to produce force rapidly and repeatedly (Paavolainen et al., 1999) and cyclists need to perform many high power spurts during the road race competitions (Jeukendrup et al., 2000; Ebert et al., 2006). Running and cycling activity is mainly performed by muscle contraction of the lower limbs, but they have different movement, kinetic and muscle activation patterns. In running (Kyröläinen et al., 2000) the knee and hip joints are more extended during the power production phase than in cycling (Bini and Diefenthaeler, 2010). The peak force applied in one cycle in submaximal conditions is more than 5 times higher during running, measured as a ground reaction force (Kyröläinen et al., 1999) than in cycling, measured as a pedal force (Farrell et al., 2003). Also the peak joint moments and power patterns in ankle, knee and hip joints are different during running stance phase than in pedal cycle at steady-state submaximal (Schache et al., 2011; Bini & Diefenthaeler, 2010; Elmer et al., 2011; William et al., 2012) and at sprinting conditions (Bezodis et al., 2012; Martin & Brown, 2009; Vrints et al., 2011; Elmer et al., 2011). The main muscle groups that are involved in cycling and running are the knee extensors and ankle plantar flexors, respectively, but in contrast to cycling, which includes mainly concentric contractions, during running the eccentric muscle actions play an important role (Bijker et al 2002; William et al., 2012).

It is known that sprint and endurance training adapt local (single joint) and global (multi joint) muscle strength patterns in different way (Harrisson et al., 2004; Lattier et al., 2003), but how can different types of endurance activities influence muscle strength adaption? Farup et al. (2012) find that 10 weeks endurance cycling training did not change isokinetic strength and force-velocity curve of knee extensors and flexors. In opposite way, Buśko et al. (2008) conclude that the four week intensive endurance training with different cadences, carried out on the cycle ergometer, caused the increase of the isometric torque of hip extensors, knee extensors and ankle plantar flexors, but lowered the torque of hip flexors and knee flexors. No analogues researches about a local strength adaption in endurance running training were found, but Lattier et al. (2003) compared competitive level endurance runners with sedentary population and did not found significant differences in knee extensors and ankle plantar flexors isometric strength and counter-movement jump performance. Another studies of Kanehisa et al. (1997) and Sleivert et al. (1995) found similar maximal strength and force-velocity values between middle-distance runners and age-matched untrained subjects. Izquierdo et al. (2002) compared half-squat results between high level athletes of different sports and conclude that middle distance runners have lower maximal concentric one repetition maximum (RM) strength and average power output at the load of 30% of 1RM compared with cyclists. Also maximal power output was achieved with load of 60% by runners and with 45% of 1RM by cyclists (Izquierdo et al., 2002). But local strength differences between cyclists and runners are not known. Only So et al. (1994) have been declared that running and jumping athletes (soccer players and gymnasts) had significantly higher dorsiflexion/plantar-flexion peak torque ratio than the cyclists, but no significant strength differences were demonstrated. The differences of lower limb extensors and flexor muscle performance, strength ratios and power-velocity curves between competitive middle distance runners and road cyclists are not known.

The aim of this study was to compare the local isokinetic muscle performance of lower limbs in middle distance runners and road cyclists.

Material and methods

Participants. The study participants were 10 competitive male middle distance runners of age ranging from 18 to 28 (mean age ± SD: 23.8 ± 3.8 years, height 181.8 ± 2.8cm, mass 73.6 ± 7.4kg) and 16 competitive male road cyclists of age ranging from 18 to 32 (21.1 ± 3.5 years, 181.5 ± 5.0cm, 74.8 ± 7.0kg). The age, height and body mass did not differ statistically ($p<0.05$) between runners and cyclists group. All athletes had at least 6 years focused endurance running or cycling training and competition experience. 4 Road cyclists were Estonian national junior (U18) and 7 cyclists U23 team members, 3 were national elite level amateur and 2 professional road cyclists from Pro Tour and Pro continental level teams. Middle distance runners mean 800m and 1500m track running outdoor season personal best results were 117.1 ± 4.6 and 242.7 ± 8.5 seconds respectively.

All participants were informed about the research procedures, requirements, benefits and risks before the testing. All participants were asked not to do a heavy or intensive training at least two days before the testing. The study was performed in November 2011 after the end of competitive season and before the start of new preparation period for cyclists and runners.

Procedures. A HUMAC 2009 NORM (Computer Sports Medicine, Inc. Stoughton, MA, USA) isokinetic dynamometer was used for the strength testing. Testing was made by one investigator and one assistant. All participants had familiarisation session with the testing equipment before testing and had before and during testing instructions how to make exercise correctly.

The ankle plantar flexors, ankle dorsi flexors, knee and hip extensors and flexors of both legs were tested accordingly. All tests procedures, dynamometer settings and securing of subjects to seat and measurement arms were carried out in accordance with the HUMAC NORM user manual. Ankle plantar and dorsi flexion tests were performed in the “Modified Seated” (supine) position, knee extension and flexion tests in seated position and hip extension and flexion tests in lying position.

The axis of rotation of the dynamometer lever arm was aligned with the anatomical axis of the joint being tested, as described in the HUMAC NORM test manual. The “gravity correction” features were used in all tests to avoid gravity effect of limb weight.

Before testing, all participants warmed up for 10 to 15min on a cycle ergometer. All tests were performed concentrically at three different velocities (60°/sec, 180°/sec and 240°/sec). For familiarization purposes, each velocity had 4 trials before the five (at 60°/sec and 180°/sec velocity) or fifteen (at 240°/sec velocity) repetitions of maximal joint flexion-extension. A recovery period of 20s between trail and test repetitions, 60 s between test velocities, 5min between body sides and 10min between different joint actions was used.

Measures. Measurement and initial analysis of isokinetic strength test variables were carried out in “HUMAC2009 NORM Application Program”. The highest peak torque (expressed in Nm) and power (W) values of best repetition from all joint actions and testing speeds and total work (J) of 15 repetitions in angular speed 240°/s were analyzed. Because the lower limb strength is depending on body weight, the relative torque (Nm/kg), power (W/kg) and total work (J/kg) were also analyzed. The deficit variables (torque difference in per cent) between body sides, muscle group strength ratios between antagonists and rate of strength maintenance in per cent between testing velocities for all muscle groups were computed. Isokinetic strength values were expressed as mean of dominant and nondominant leg.

Analysis. Microsoft Excel add-on „Statistics” were used for data analysis. Descriptive data were computed for both groups separately and expressed as mean ± standard deviation (SD). All the data was tested for their normal distribution (Kolmogorov - Smirnov test) and the differences between dispersion of compared groups were tested with F-test. Two tails Student's t-tests were used to assess the differences of absolute and relative isokinetic performance variables between runners and cyclists groups. A Student's t-test for paired data was applied to compare muscle groups power values of different testing velocities in cyclists and runners groups separately. Significance level was set at p<0.05 for all analyses.

Results

The isokinetic muscle peak torque and relative peak torque average results of runners and cyclists are shown in Table 1. Cyclists had significantly (p<0.05) higher ankle plantar flexors relative peak torque values in testing speeds 60 and 240°/s, but had similar tendency (p=0.08) in speed 180°/s. The knee flexors relative strength was significantly higher in cyclists group in all tested velocities and absolute strength in testing speeds 180 and 240°/s, but had similar tendency (p=0.08) in 60°/s. No significant differences in ankle dorsi flexors, knee extensors and hip extensors and flexors peak torque values at any speed were find between runners and cyclists.

Table 1

Absolute (Nm) and relative (Nm/kg) peak torque values of all tested muscle groups and testing velocities in middle distance runners (n=10) and road cyclists (n=16) group (mean ± SD)

Joint	Velocity	Absolute peak torque values (Nm)			Relative peak torque values (Nm/kg)		
		Runners (n=10)	Cyclists (n=16)	p - value	Runners (n=10)	Cyclists (n=16)	p - value
Ankle PF	60 °/s	87.5 ± 32.5	107.6 ± 22.4	0.09	1.17 ± 0.36	1.43 ± 0.22	0.04*
	180 °/s	58.2 ± 15.9	68.6 ± 16.6	0.16	0.79 ± 0.17	0.91 ± 0.16	0.08
	240 °/s	55.5 ± 14.0	66.8 ± 14.8	0.09	0.75 ± 0.14	0.89 ± 0.15	0.04*
Ankle DF	60 °/s	30.1 ± 6.4	27.8 ± 4.8	0.33	0.41 ± 0.07	0.38 ± 0.06	0.17
	180°/s	27.6 ± 7.2	28.2 ± 6.2	0.84	0.37 ± 0.07	0.38 ± 0.07	0.86
	240 °/s	27.0 ± 6.3	26.7 ± 6.3	0.90	0.37 ± 0.06	0.36 ± 0.06	0.74
Knee EX	60°/s	199.3 ± 26.8	222.7 ± 35.4	0.11	2.72 ± 0.35	2.98 ± 0.41	0.14
	180°/s	148.7 ± 16.0	158.6 ± 24.6	0.32	2.03 ± 0.19	2.13 ± 0.31	0.40
	240 °/s	127.1 ± 11.5	135.7 ± 21.3	0.30	1.74 ± 0.16	1.82 ± 0.26	0.42
Knee FL	60°/s	110.8 ± 22.3	128.8 ± 22.6	0.08	1.50 ± 0.22	1.72 ± 0.24	0.04*
	180 °/s	81.8 ± 11.6	95.2 ± 13.7	0.03*	1.11 ± 0.14	1.28 ± 0.17	0.03*
	240°/s	67.2 ± 13.5	84.2 ± 13.1	0.01*	0.92 ± 0.18	1.13 ± 0.15	0.01*
Hip EX	60 °/s	282.3 ± 58.7	316.5 ± 71.3	0.25	3.83 ± 0.61	4.21 ± 0.68	0.20
	180 °/s	223.2 ± 50.0	246.5 ± 49.1	0.29	3.02 ± 0.49	3.29 ± 0.46	0.21
	240°/s	207.0 ± 39.1	220.0 ± 37.3	0.44	2.81 ± 0.39	2.94 ± 0.33	0.41
Hip FL	60°/s	175.9 ± 31.0	170.9 ± 21.8	0.65	2.39 ± 0.33	2.30 ± 0.27	0.46
	180 °/s	138.1 ± 26.0	131.0 ± 16.5	0.42	1.88 ± 0.32	1.76 ± 0.22	0.31
	240 °/s	122.6 ± 24.1	115.4 ± 15.3	0.38	1.67 ± 0.30	1.55 ± 0.22	0.29

DF - dorsi flexors; PF – plantar flexors; EX – extensors; FL - flexors
*- significantly different between cyclists and runners (p<0.05)

The comparison of average power values (Table 2) of best repetitions gave almost similar differences between cyclists and runners – cyclists had higher relative and absolute average power in knee flexors at all speeds and higher relative values of ankle plantar flexors in 60°/s and 240°/s. But in power values the cyclists had significantly higher relative and absolute results of knee extensors at 60°/s and had also tendency (p=0.08) for higher relative hip extensors power in testing speed of 60°/s and knee extensors power (p=0.08) in velocity of 240°/s.

Table 2

Absolute (W) and relative (W/kg) average power values of all tested muscle groups and testing velocities in middle distance runners (n=10) and road cyclists (n=16) group (mean ± SD)

Joint	Velocity	Absolute power values (W)			Relative power values (W/kg)		
		Runners (n=10)	Cyclists (n=16)	p - value	Runners (n=10)	Cyclists (n=16)	p - value
Ankle PF	60 °/s	50.3 ± 19.0	64.8 ± 15.2	0.05	0.67 ± 0.21	0.86 ± 0.15	0.02*
	180 °/s	81.8 ± 25.9	99.5 ± 27.7	0.15	1.10 ± 0.29	1.32 ± 0.29	0.10
	240 °/s	89.8 ± 26.6	112.8 ± 29.2	0.07	1.21 ± 0.29	1.50 ± 0.31	0.04*
Ankle DF	60 °/s	19.8 ± 4.1	18.5 ± 3.3	0.44	0.27 ± 0.05	0.25 ± 0.04	0.30
	180 °/s	26.4 ± 7.7	26.9 ± 5.5	0.86	0.36 ± 0.09	0.36 ± 0.06	0.91
	240 °/s	25.1 ± 7.0	26.7 ± 6.3	0.57	0.34 ± 0.08	0.35 ± 0.07	0.65
Knee EX	60 °/s	140.3 ± 12.7	160.3 ± 25.8	0.05*	1.92 ± 0.20	2.15 ± 0.27	0.05*
	180 °/s	269.9 ± 29.4	296.0 ± 42.7	0.14	3.68 ± 0.33	3.97 ± 0.49	0.15
	240 °/s	270.7 ± 31.8	302.5 ± 46.3	0.10	3.70 ± 0.36	4.05 ± 0.49	0.09
Knee FL	60 °/s	79.5 ± 15.3	99.2 ± 16.1	0.01*	1.08 ± 0.16	1.32 ± 0.16	0.00*
	180 °/s	148.3 ± 21.8	182.9 ± 25.7	0.00*	2.02 ± 0.26	2.45 ± 0.31	0.00*
	240 °/s	145.1 ± 30.5	189.1 ± 32.8	0.00*	1.98 ± 0.42	2.53 ± 0.39	0.00*
Hip EX	60 °/s	193.9 ± 36.8	226.0 ± 50.9	0.13	2.63 ± 0.37	3.01 ± 0.51	0.08
	180 °/s	400.3 ± 93.3	445.3 ± 91.2	0.27	5.42 ± 0.97	5.93 ± 0.89	0.21
	240 °/s	415.8 ± 89.3	443.3 ± 78.0	0.45	5.65 ± 0.99	5.92 ± 0.77	0.46
Hip FL	60 °/s	110.0 ± 16.3	111.3 ± 16.6	0.86	1.50 ± 0.21	1.49 ± 0.19	0.91
	180 °/s	218.2 ± 34.3	211.8 ± 31.7	0.65	2.98 ± 0.42	2.84 ± 0.40	0.44
	240 °/s	227.8 ± 43.2	218.3 ± 33.1	0.55	3.11 ± 0.55	2.93 ± 0.40	0.37

DF - dorsi flexors; PF – plantar flexors; EX – extensors; FL - flexors
*- significantly different between cyclists and runners (p<0.05)

No significant differences in ankle dorsi flexors and hip flexors average power values at any speed were found. Also the significance of differences between runners and cyclists in hip extensors power values lowered with increase of testing velocities.

In Table 3 are expressed the total work values of 15 repetitions in testing velocity 240°/s, this data is expressing the local muscular speed endurance abilities of tested muscle groups. Cyclists had significantly higher total work abilities of ankle plantar flexors (relative values) and knee extensors and flexors (absolute and relative values), but runners had significantly better relative results of hip flexors. No statistical differences between runners and cyclists were observed in the local speed endurance of ankle dorsi flexors and hip extensors.

Table 3

Absolute (J) and relative (J/kg) total work values of 15 repetitions in testing velocities 240^0 /s at all tested muscle groups in middle distance runners (n=10) and road cyclists (n=16) group (mean ± SD)

Joint	Absolute total work of 15 repetition (J)			Relative total work of 15 repetition (J/kg)		
	Runners (n=10)	Cyclists (n=16)	p - value	Runners (n=10)	Cyclists (n=16)	p - value
Ankle PF	452.4 ± 155.0	571.3 ± 139.5	0.07	6.12 ± 1.80	7.61 ± 1.54	0.05*
Ankle DF	139.0 ± 35.8	147.9 ± 27.6	0.51	1.88 ± 0.41	1.99 ± 0.35	0.52
Knee EX	1991.1 ± 246.6	2294.4 ± 372.1	0.05*	27.16 ± 2.79	30.76 ± 4.40	0.05*
Knee FL	944.5 ± 217.6	1342.5 ± 229.0	0.00*	12.95 ± 3.18	18.02 ± 2.95	0.00*
Hip EX	3232.5 ± 840.0	3307.8 ± 688.8	0.82	43.82 ± 9.30	44.24 ± 7.80	0.91
Hip FL	1719.4 ± 354.0	1496.2 ± 199.6	0.06	23.51 ± 4.69	20.14 ± 2.80	0.04*

DF - dorsi flexors; PF – plantar flexors; EX – extensors; FL - flexors

*- significantly different between cyclists and runners (p<0.05)

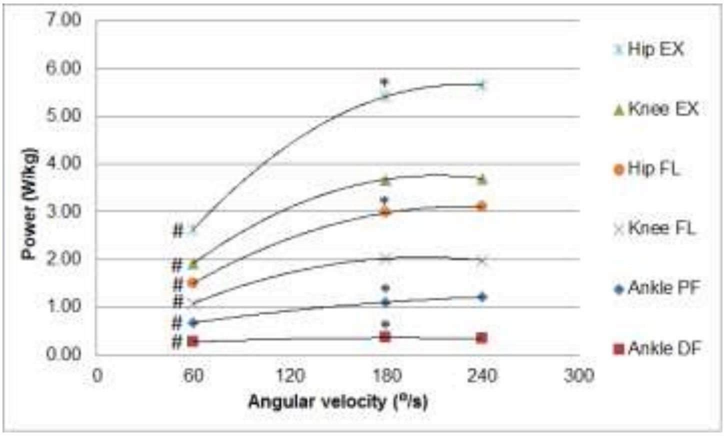
The comparison of antagonistic muscle group ratios (Table 4) show that runners have significantly more balanced ankle dorsi flexors-plantar flexors ratio (in velocities 60°/s and 240°/s) and cyclists have more equally balanced knee flexors-extensors ratio in velocity of 240°/s, but same tendency (p=0.06) is also in velocity of 180°/s. No statistical differences in hip extensors-flexors ratios between runners and cyclists were found, but there is a tendency (p=0.08) for higher ratios in cyclists group at low (60°/s) velocity.

Table 4

Antagonistic muscle group ratios of all tested joints and testing velocities in middle distance runners (n=10) and road cyclists (n=16) group (mean ± SD)

Joint	Velocity	Peak torque ratio (%)		
		Runners (n=10)	Cyclists (n=16)	p-value
Ankle DF/PF	60 °/s	37.6 ± 9.3	26.4 ± 3.9	0.00*
	180 °/s	49.7 ± 13.9	42.3 ± 10.7	0.16
	240 °/s	50.2 ± 9.7	40.8 ± 7.2	0.01*
Knee FL/EX	60 °/s	55.6 ± 6.9	57.9 ± 4.2	0.32
	180 °/s	55.1 ± 5.9	60.5 ± 6.4	0.06
	240°/s	53.0 ± 8.8	62.5 ± 7.2	0.01*
Hip EX/FL	60°/s	161.1 ± 18.5	185.5 ± 34.9	0.08
	180 °/s	164.3 ± 35.1	189.7 ± 38.2	0.13
	240°/s	173.1 ± 37.1	192.3 ± 30.3	0.19

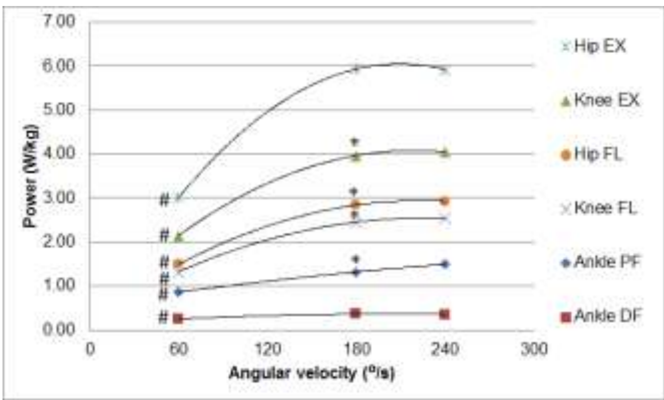
*- significantly different between cyclists and runners (p<0.05)



(# - significantly lower than 180°/s and 240°/s; * - significantly lower than 240°/s)

Figure 1. Power-velocity curves of tested muscle groups in runners group (n=10)

The power-velocity curves of middle distance runners (Figure 1) and road cyclists (Figure 2) are showing that power achieved at velocity of 60°/s is in all cases and in both groups significantly lower than power achieved at higher velocities. Ankle plantar flexors and hip flexors power is significantly highest at velocity of 240°/s in both groups. At hip extensors and ankle dorsi flexors have runners significantly stronger power values also at velocity of 240°/s, but cyclists have no significant differences ($p=0.37$ and $p=0.40$ respectively) between results at velocities of 180°/s and 240°/s. Reversely cyclists have significantly stronger power values in knee extensors and flexors at velocity of 240°/s and runners have no significant differences ($p=0.46$ and $p=0.31$ respectively) between results at velocities of 180°/s and 240°/s.



(# - significantly lower than 180°/s and 240°/s; * - significantly lower than 240°/s)

Figure 2. Power-velocity curves of tested muscle groups in cyclists group (n=10)

Discussion

The purpose of this study was to compare the isokinetic muscle performance of lower limbs between middle distance runners and road cyclists. Main differences in local muscle performance between runners and cyclists were in strength, power and speed endurance values of knee flexors and ankle plantar flexors, in where the cyclists achieved higher results. Cyclists had also better knee extensors power at low velocity and larger speed endurance at velocity of 240°/s. Our findings are partly, in case of knee extensors and ankle planter flexors, supported by research of Izquierdo et al. (2002) who showed that highly trained amateur road cyclists had, compared with same level middle-distance runners, higher leg extensors maximal strength and power in low resistance conditions.

Buśko et al. (2008) found that the cycle ergometer training elicits the hip extensors isometric torque growth in low and moderate cadence and in endurance and sprint regime, but did not influence knee flexors torque at any condition. The data of the present study showed that cyclists have significantly stronger knee flexors than runners. But Cyclists had only tendency to higher power values at hip extensors in velocity of 60°/s, compared to runners. If we assume, that middle-distance runners maximal strength values are not significantly different of untrained subjects (Kanehisa et al., 1997; Sleivert et al., 1995; Lattier et al., 2003), then we can speculate that our results show different adaption patterns created by long term, high amount and variable intensity of training and competition loads (Jeukendrup et al., 2000; Ebert et al., 2006) in specific road cycling position. The significant higher knee flexors performance values and lower hip flexors total work results of cyclists may due from lower upper-body position (Bini and Diefenthaeler, 2010) and pedalling movement. In conditions of low upper body position and closed hip angles, used in competitive cycling (Bini and Diefenthaeler, 2010), the biarticular knee flexors are more stretched and hip flexors shortened than in running and this affects muscle morphology and muscle fibres length (Brughelli et al., 2010 ; Savelberg and Meijer 2003). Also knee extensors are more loaded on a second half of pedalling pushing phase than in the stance phase during running (Bijker et al., 2002). Upper body position also affects the ankle plantar and dorsi flexors activation and coactivation (Chapman et al., 2008) - this may be one factor why cyclists have relatively higher plantar flexors performance. Also cyclists had lower ankle dorsi and plantar flexors ratio – this is similar to So et al. (1994) findings who declared that running and jumping athletes need to stabilise ankle joint and for this reason they have more balanced dorsi-flexion/plantar-flexion strength ratio.

This study found also different patterns of power-velocity relationships between muscle groups of cyclists and runners. Runners achieved best power values at hip extensors and ankle dorsi flexors in higher velocity than cyclists and cyclists achieved best power values in higher velocities at knee extensors and flexors. Izquierdo et al. (2002) found also that cyclists achieved maximal power output in half squat, where mainly knee extensors are in use, with lower resistance and higher speed than runners.

Conclusions

We found that cyclists have higher isokinetic muscle performance values in ankle plantar flexors, knee extensors and flexors and runners have higher speed endurance ability of hip flexors. No significant differences in ankle dorsi flexors and hip extensors performance between cyclists and runners were found. Runners had more balanced ankle dorsi flexors - plantar flexors ratio and cyclists had higher knee flexors-extensors ratio. Middle distance runners and road cyclists have also different power-velocity patterns of ankle dorsi flexors, knee extensors, knee flexors and hip extensors.

References

1. Bezodis, N. E., Salo, A. T., & Trewartha, G. (2012). Modeling the Stance Leg in Two-dimensional Analyses of Sprinting: Inclusion of the MTP Joint Affects Joint Kinetics. *Journal Of Applied Biomechanics, 28*(2), 222-227.
2. Bijker, K. E., de Groot, G. G., & Hollander, A. P. (2002). Differences in Leg Muscle Activity During Running and Cycling in Humans. *European Journal Of Applied Physiology, 87*(6), 556-561. DOI 10.1007/s00421-002-0663-8
3. Bini, R. R., & Diefenthaeler, F. (2010). Kinetics and Kinematics Analysis of Incremental Cycling to Exhaustion. *Sports Biomechanics, 9*(4), 223-235.
4. Brughelli, M., Cronin, J., Nosaka, K. (2010) Muscle Architecture and Optimum Angle of the Knee Flexors and Extensors: a Comparison Between Cyclists and Australian Rules Football Players. *Journal Of Strength & Conditioning Research, 24*(3):717-21.
5. Buśko, K. K., Madej, A. A., & Mastalerz, A. A. (2008). Changes of Muscle Torque after Sprint and Endurance Training Performed on Cycle Ergometer. *Biology Of Sport, 25*(3), 275-294.
6. Chapman, A. R., Vicenzino, B., Blanch, P., Knox, J. J., Dowlan, S., Hodges, P. W. (2008) The Influence of Body Position on Leg

Kinematics and Muscle Recruitment During Cycling. *Journal Of Science and Medicine in Sport, 11*(6):519-26.

7. Elmer, S. J., Barratt, P. R., Korff, T., & Martin, J. C. (2011) Joint-Specific Power Production during Submaximal and Maximal Cycling. *Medicine & Science in Sports & Exercise, 43*(10): 1940-1947.
8. Farrell, K. C., Reisinger, K. D., & Tillman, M. D. (2003) Force and Repetition in Cycling: Possible Implications for Iliotibial Band Friction Syndrome. *Knee, 10*(1):103-9.
9. Farup, J., Kjølhede, T., Sørensen, H., Dalgas, U., Moller, A. B., Vestergaard, P. F., & Vissing, K. (2012). Muscle Morphological and Strength Adaptations to Endurance vs. Resistance Training. *Journal Of Strength & Conditioning Research, 26*(2), 398-407.
10. Gottschall, J. S., & Kram, R. (2005). Ground Reaction Forces During Downhill and Uphill Running. *Journal Of Biomechanics, 38*(3), 445-452.
11. Harrison, A. J., Keane, S. P., & Coglan, J. (2004). Force-velocity Relationship and Stretch-shortening Cycle Function in Sprint and Endurance Athletes. *Journal Of Strength & Conditioning Research, 18*(3), 473-479.
12. Izquierdo, M., Häkkinen, K., Gonzalez-Badillo, J. J., Ibáñez, J., & Gorostiaga, E. M. (2002) Effects of Long-term Training Specificity on Maximal Strength and Power of the Upper and Lower Extremities in Athletes from Different Sports. *European Journal Of Applied Physiolgy, 87*(3):264-71.
13. Jeukendrup, A. E., Craig, N. P., & Hawley, J. A. (2000). The Bioenergetics of World Class Cycling. *Journal Of Science & Medicine In Sport, 3*(4), 414-433.
14. Kanehisa, H. H., Ikegawa, S. S., & Fukunaga, T. T. (1997). Force-velocity Relationships and Fatiguability of Strength and Endurance-Trained Subjects. *International Journal Of Sports Medicine, 18*(2), 106-112.
15. Kyröläinen, H., Komi, P.V., & Belli, A. (1999) Changes in Muscle Activity Patterns and Kinetics with Increasing Running Speed. *Journal Of Strength & Conditioning Research,13*(4): 400–406.
16. Kyröläinen. H., Pullinen, T., Candau, R., Avela, J., Huttunen, P., Komi, P. (2000) Effects of Marathon Running on Running Economy and Kinematics. *European Journal Of Applied Physiolgy, 82*:297–304

17. Lattier, G., Millet, G. Y., Maffiuletti, N. A., Babault, N., Lepers, R. (2003) Neuromuscular Differences Between Endurance-trained, Power-trained, and Sedentary Subjects. *Journal Of Strength & Conditioning Research, 17*(3), 514-21.
18. Martin, J. C., & Brown, N. T. (2009). Joint-specific Power Production and Fatigue During Maximal Cycling. *Journal Of Biomechanics*, *42*(4), 474-479.
19. Paavolainen, L. M., Nummela, A. T., & Rusko, H. K. (1999). Neuromuscular Characteristics and Muscle Power as Determinants of 5-km Running Performance. *Medicine & Science In Sports & Exercise, 31*(1), 124-130.
20. Savelberg, H.H., Meijer, K. (2003) Contribution of Mono- and Biarticular Muscles to Extending Knee Joint Moments in Runners and Cyclists. *Journal Of Applied Physiolgy, 94*(6):2241-8.
21. Schache, A. G., Blanch, P. D., Dorin, T. W., Brown, N. A. T., Rosemond, D., & Pandy, M. G. (2011) Effect of Running Speed on Lower Limb Joint Kinetics. *Medicine & Science in Sports & Exercise. 43*(7), 1260–1271.
22. Sleivert, G. G., Backus, R. D., & Wenger, H. A. (1995). Neuromuscular Differences Between Volleyball Players, Middle Distance Runners and Untrained Controls. *International Journal Of Sports Medicine*, *16*(6), 390-398.
23. So, C. H., Siu, T. O., Chan, K. M., Chin, M. K., & Li, C. T. (1994). Isokinetic Profile of Dorsiflexors and Plantar Flexors of the Ankle - a Comparative Study of Elite Versus Untrained Subjects. *British Journal Of Sports Medicine*, *28*(1), 25-30.
24. Vrints, J., Koninckx, E., Van Leemputte, M., & Jonkers I. (2011) The Effect of Saddle Position on Maximal Power Output and Moment Generating Capacity of Lower Limb Muscles During Isokinetic Cycling. *Journal Of Applied Biomechanics, 27*(1), 1-7.
25. William, D. S. 3rd, Green, D. H., & Wurzinger, B. (2012). Changes in Lower Extremity Movement and Power Absorption During Forefoot Striking and Barefoot Running. *International Journal Of Sports Physical Therapy, 7*(5), 525-532.

Submitted: April 15, 2013
Accepted: October 31, 2013