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Isokinetic muscle strength and short term cycling power of road cyclists

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ABSTRACT

Rannama I, Bazanov B, Baskin K, Zilmer K, Roosalu M, Port KJ. Isokinetic muscle strength and short term cycling power of road cyclists. *J. Hum. Sport Exerc.* Vol. 8, No. Proc2, pp. S19-S29, 2013. The ability to produce maximal short term power plays important role in success and tactical economy in competitive road cycling. There are no current studies relating the isokinetic strength parameters of lover limb muscles to sprinting power in high level competitive cyclists. The purpose of this study was to characterise lower body muscles strength among high level cyclists and examine the relationship between isokinetic muscle strength and cycling sprinting power. Power output of 17 high level road cyclists (age 20.5±3.8 yrs., mass 180.8±5.7 cm, height 74.3±7.0 kg) was measured with the help of isokinetic test on a Cyclus2 Ergometer. Also isokinetic strength of ankle plantar flexors, ankle dorsal flexors, knee and hip extensors and flexors were measured with Humac NORM isokinetic dynamometer in angular speeds 60, 180 and 240º/s. The hip extensors were the strongest muscle group in all measured velocities, followed by knee extersors and hip flexors, the weakest muscle group was ankle dorsi flexors. Hip extensors torque at 180º/s was strongly correlated (r=0.9 between absolute values and r=0.74 between relative to body weight values) with short term cycling power while other muscle group demonstrated weaker relationship. Relative strength of hip flexors and ankle dorsi flexors did not show meaningful relationship with sprinting power after correction with riders body weight. In conclusion, the strongest muscle group in road cyclists are hip extensors, sprinting power has strongest correlation with hip extensors strength at angular speed of 180º/s, relationship between sprinting power and strength of hip flexors was statistically insignificant. **Key words**: CADENCE, CYCLUS-2 ERGOMETER, PEAK TORQUE, ISOKINETIC DYNAMOMETRY.

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INTRODUCTION

The ability to produce high power during a short period of time is an important component of success (Jeukendrup et al., 2000) and of tactical arsenal in road cycling competitions. Ebert et al. (2006) demonstrated that in professional mass start road cycling competitions most sprints last up to 10 seconds and 20-70 sprints above maximum aerobic-power output during different types of racing are common.

The ability to produce power in cycling is influenced by bicycle set up according to cyclist's anthropometry (Gonzalez & Hull, 1989). The seating position on the bicycle affects cycling movement as reflected in the joint kinematics, and therefore the power generating capabilities (Too, 1990; Vrints et al., 2011; Yoshihuku & Herzog, 1990). Higher saddle positions (109% of inner leg length or 102% greater than trochanter height) are reported to be more effective for power production (Rankin & Neptune, 2010; Vrints et al., 2011). Lower saddle positions affects knee joint kinematics, compromising mechanical performance of major muscle groups acting at the knee (Vrints et al., 2011).

Maximal cycling power output largely depends on the movement speed that in cycling is expressed as cadence. The maximal peak power output during 10 s sprints show higher values in pedalling rates at 100 rpm and 120 rpm and are lower in cadences of 60, 80 and 140 rpm (Zoladz et al., 2000). Van Soest and Casius (2000) found in musculoskeletal modelling that best cadence to achieve short time maximum power is near 120 rpm. Evidence shows that during trek competitions world top sprinters attain maximum power output at pedalling rate near 129±9 rpm (Dorel et al., 2005; Gardner et al., 2007). The effectual or optimal cadence depends on cycling experiences (Coast & Welch, 1985; Marsh & Martin, 1995), muscle fibre type distribution in lower limb muscles (Ahlquist et al. 1992; Hansen et al., 2002; Umberger et al., 2006), bicycle crank length (Martin & Spirduso, 2001), cyclists age and power level (Rannama et al., 2012), but there is substantial lack of information regarding relationship between effectual cadence and strength variables of lower limb muscles.

The relative deployment of lower limb muscle groups in sprinting is dependent on cadence. Elmer et al. (2011) found that inverse of dynamically computed absolute hip extension power increased by 19% between maximal cycling trials with 90 and 120rpm whereas knee extension and knee flexion powers did not differ. The muscle group involvement is also related with exercise intensity. During submaximal cycling dominating muscles are knee extensors (Ericson, 1988). Broker and Gregor (1994) reported that muscular power of hip accounted for 8.7% of total power, whereas ankle and knee power accounted for 12.3 and 72.1%, respectively, when cycling at 250W and 90 rpm. However,during maximal cycling larger portion of power is generated by hip extensors that produced nearly twice the power compared to knee extension (Martin & Brown, 2009). With increasing power output during cycling relatively less knee extension and more knee flexion power will be produced (Elmer et al., 2011). Also the fatigue during maximal cycling occurred at different rates - the ankle joint power tends to decrease more rapidly than power deteriorates at other lower limb joints, hip extensors sustain their power longer and at higher rate (Martin & Brown, 2009). Therefore one could assume that adaptation of cyclist's lower body muscle can be detected via their functional strength capacity. Based on available submaximal cycling power data at various joints it is expected that muscles over knee are under highest adaptive pressure because during most of training and competition cyclists are working at the submaximal workloads. It is also expected that hip extensor muscles are stronger and more fatigue resistant at maximal cycling loads. Question remains if the adaptation of cyclists muscle group maximum isokinetic strength values are in accordance to patterns characteristic to deployment during sprint cycling or to patterns that are typical in submaximal cycling – what is the relationship between lower limb muscle isokinetic strength and cycling power?

It has been reported that among young non cycling athletic population the 30 seconds Wingate test peak and mean absolute and relative power is substantially related with leg multi joint isometric (Arslan, 2005) and explosive strength (jumping performance) (Arslan, 2005; Alemdaroglu, 2012). Sanding et al. (2008) tested junior road cyclists and found a strong correlation between maximum 10 seconds isokinetic power output and maximum multi joint extensors isometric strength at race specific cadences (80-120 rpm), no correlations were found with power achieved at cadences of 60 and 140 rpm. Stone et al. (2004) showed that track sprint cyclists isometric mid-thigh pull strength (both absolute and relative to body mass) and the peak rate-of-force development were strongly correlated with 18 seconds Wingate test power and sprint cycling times.

Isokinetic dynamometers have lately been introduced used to assess the role of different muscle group's strength in sprint cycling power production. In basketball players is was found that maximal veloergometer cycling power was moderately related with knee extensors isokinetic strength in velocities 60 and 180º/s, but no significant correlations were found with knee flexors (Alemdaroglu, 2012) – but is not known what kind of pedals were used. Smith (1987) found that in active young male cyclists mean 30 seconds Wingate cycling test power correlated with isokinetic peak torque at 180 ◦/s for knee flexion ($r = 0.96$) and extension ($r = 0.87$) and also with hip flexion ($r = 0.71$) and extension ($r = 0.68$).

The literature regarding relationships between dynamic strength of different muscle groups and cycling sprinting performance of competitive road cyclists is extremely limited and most studies have documented cycling power relationships with strength of multi joint actions in isotonic-explosive or isometric conditions. The isokinetic strength is mostly related with cycling power in non-cyclist athletic population. For this reason there is lack of information available regarding isokinetic strength of road cyclists and even less is known how the sprint power is related with isokinetic strength of main lower limb muscles in different angular velocity conditions.

The purpose of this study was to clarify the adaption of road cyclist's lower body muscles strength and examine the relationship between isokinetic muscle strength and cycling sprinting power.

MATERIAL AND METHODS

Participants

The study participants were 17 competitive male high level road cyclists: 5 cyclists were national junior (U18) and 7 cyclists U23 team members, 3 were national elite level amateur cyclists and 2 were professional road cyclists from Pro Tour and Pro continental level teams. All cyclists went through anthropometrical measurements (mean±SD): age 20.7±3.7 yrs., height 180.8±5.7 cm, body weight 74.3±7.0 kg. All cyclists had a at least 6 years focused cycling training and competition experience and had no general (done without bicycle) strength training history in last 6 month.

Procedures

Experimental protocol consisted of 2 separate phases: cycling sprint power tests in 3 cadence conditions and isokinetic strength testing of six lower limb muscle groups in 3 angular velocity condition. Both experimental phases were performed during the same day - each subject completed first cycling tests and after 5 minutes easy cycling and 10 minutes of passive recovery was followed with isokinetic strength testing. The experimental phase was performed in the end of cycling season during the cyclist's recovery period.

Cycling sprint power protocol. All tests were performed using the participants personal racing bike, which was mounted on research grade cycling ergometer platform Cyclus 2 (Avantronic , Cyclus 2, Leipzig, Germany) that allows lateral incline of the bike that matches real life cycling. The warm-up consisted of 10 minutes of steady ride in power level of 100 W, 5 minutes riding with progressively increasing power from 100W to the level of 4W/kg, 2 minutes in level of 4W/kg, 3 minutes steady ride in power level of 100 W and one 6 seconds of isokinetic maximal sprint with cadence set in 100 rpm followed 4 minutes recovery ride. After warm-up three separate bouts of sprint efforts with 4 minute rest periods in isokinetic mode were conducted. Four minute rest is shown to be sufficient for recovery (Billaut, Giacomoni et al. 2003). In isokinetic cycle ergometry, the braking forces used to maintain the same cadence were originally achieved by driving the pedals at a constant speed. For the testing three target cadences were set of 100 rpm, 120rpm and 140 rpm accordingly, that covers the effectual cadence area for generating maximal power (Dorel, Hautier et al. 2005; Gardner et al. 2007, Zoladz et al. 2000, Van Soest and Casius 2000,). All tests were conducted in sitting position hands on the drops.

Isokinetic strength protocol. A HUMAC 2009 NORM (Computer Sports Medicine, Inc. Stoughton, MA, USA) isokinetic dynamometer was used for the strength tests. 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.

All joint movements were tested concentrically at velocities 60, 180 and 240º/s. At each test velocity, the subject performed 4 submaximal warm-up trials followed by 5 (60 and 180º/s) or 15 (240º/s) maximal test trials after 30 seconds recovery. A recovery period of 60 s between test velocities, 5 minutes between body sides and 10 minutes between different joint actions was used.

Measures

In cycling power test from each cadence level the absolute (expressed in W) and relative (power per kg of body weight-W/kg) maximal peak (P-max) and 10 seconds average power (P-10s) were registered. The best power values from three tests and the effectual cadence value where the best power achieved were taken to the analysis.

Measurement and initial analysis of isokinetic strength test variables were carried out in “HUMAC2009 NORM Application Program”. The highest peak torque values of best repetition from all joint actions and testing speeds of dominant and nondominant leg were analyzed as muscle group strength (expressed in Nm). The measurement of peak torque has been shown to be accurate and highly reproducible (Kannus, 1994). Because the lower limb strength is dependent on body weight, the relative torque were also analyzed (Nm/kg). The deficit variables (torque difference in percent) 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.

To further elucidate the association of sprint cycling performance with muscle group's strength variables, the athletes were divided into 2 comparison groups: the 6 highest vs. the 6 lowest relative 10 seconds power values among all test subjects. To remove the effects of body mass all strength values were normalized.

Analysis

Descriptive data were expressed as mean ± standard deviation (SD). All the data was tested for their normal distribution (Kolmogorov-Smirnov test). A Student's t-test for paired data was applied to compare maximal peak power and 10 second average power values of different cadence tests and between strength values of different muscle groups in same testing velocity. One-way ANOVA was used to assess the differences of relative isokinetic strength variables between stronger and weaker sprint power groups. Pearson product- moment correlation was used to examine the relationship between variables. To test the significance of differences between dependent correlations the Williams's T2 statistics were calculated. Significance level for all tests was set at $p<0.05$.

RESULTS

The average values of cycling sprint test results are shown in Table 1. Cyclist's best P-max during all three tests was 1233±181W and P-10s was 1013±130. Per kg of body weight the best attained power was 16.6±1.6 and 13.6±1.0 W/kg correspondingly. Comparison of the power at three different cadences revealed that average P-max and P-10s were significantly higher at 120 rpm compared with results at 100 and 140 rpm ($p<0.05$). P-max did not differ between cadences of 100 and 140rpm ($p=0.10$), but P-10s values were significantly higher at 100 rpm compared with 140 rpm ($p<0.05$). The group P-max was achieved at average cadences of 117.1±11.7 rpm and highest P-10s at 112.8±10.7 rpm.

Table 1. *Absolute (W) and relative (W/kg) peak and 10 seconds average power values of cycling sprint tests (n = 17; mean ± sd).*

	Absolute power (W)				**Relative power (W/kg)**			
	100 rpm	120 rpm	140 rpm	Best result	100 rpm	120 rpm	140 rpm	Best result
P-max	1160±160*	1212±204#	1125±199	1233±181	15.6±1.4*	16.3±2.0#	15.1±2.1	16.6±1.6
P-10s	966±128*#	998±132#	919±139	1013±130	13.0±1.1*#	13.4±1.1#	12.3±1.4	13.6±1.0

**- significantly different with 120 rpm values, # - significantly different with 140 rpm values (p<0.05)*

The isokinetic muscle strength results are shown in Table 2. All peak torques of different muscle groups for equal velocities were statistically different ($p<0.05$) from each other. The hip extensors were the strongest muscle group in all measured velocities, followed by knee extersors and hip flexors. The weakest muscle group was ankle dorsi flexors, but this muscle group had no significant differences ($p>0.09$) between strength values in all tested angular velocities. Also no significant differences ($p=0.4$) were found between torque values of ankle plantar flexors in velocities 180 and 240º/s. All hip and knee extensors and flexors torques decreased significantly ($p<0.05$) when angular velocities were increased.

Table 2. *Absolute and relative isokinetic strength data for the knee, hip and ankle joints at different velocities (n = 17; mean ± sd).*

Muscle group	Peak torque (Nm)			Relative peak torque (Nm/kg)		
	Angular velocity			Angular velocity		
	60º/s	180º/s	240º/s	60º/s	180º/s	240º/s
Ankel Plantarflexors	108±21.7	69±16.1	67±14.3	1.44±0.22	0.92±0.16	0.89±0.14
Ankel Dorsiflexors	28±4.7	28±6.1	26±6.2	0.37±0.05	0.37±0.07	0.35±0.06
Knee Extensors	223±34.2	158±23.9	135±20.6	3.00±0.41	2.13±0.30	1.83±0.25
Knee Flexors	127±23.2	94±13.7	83±13	1.7±0.24	1.27±0.17	1.12±0.15
Hip Extensors	317±69.1	247±47.6	220±36.1	4.24±0.68	3.31±0.46	2.95±0.33
Hip Flexors	166±29.8	129±18.5	114±16.3	2.23±0.37	1.74±0.23	1.54±0.22

Note: All peak torques of different muscle action for a given velocities were different from each other (p<0.05)

A number of significant relationships were found between the cycling sprint power and isokinetic strength variables, the statistically significant correlations between absolute strength and power and between body mass corrected values of peak torque and cycling power are reported in Table 4. Almost all absolute muscle group strength values were positively and significantly correlated with P-max and P-10s, except hip flexors in lower velocities with P-max (60º/s and 180º/s) and in higher (180º/s and 240º/s) velocities with P-10s. The correlations between P-max and P-10s (absolute values) were significantly different in case of knee flexors 60º/s and hip extensors 60º/s, that muscle group strength in lower velocities showed strongest relationship with longer power production than with short time power peak. Correlations between P-max and P-10-s of other torque values did not differ significantly ($p>0.14$). Also the correlations between power and torque values were no different ($p>0.06$) between testing velocities in any muscle group. Comparing the differences in correlations between muscle groups in all testing velocities showed that strongest ($p<0.05$) relationship with P-10s have hip extensors strength in 180º/s. Also the hip extensors correlations between P-max and P-10s were in any testing velocities significantly ($p<0.05$) higher than hip flexors correlations.

The cycling power were strongly related with cyclists body mass (P-max, $r=0.78$ and P-10s, $r=0.81$). To eliminate the effect of body mass also the correlations between strength and power values normalized to body mass were computed. Between relative values the P-max and P-10s correlated significantly with hip and knee extensors in all velocities and P-max were correlated with ankle plantar flexors in velocities 60º/s and 240º/s. Knee flexors relative strength correlated significantly only with P-10s values.

It was also found that there is negative correlation between cyclists power and knee extensors peak torque contralateral deficit (group average 7.5±4.2% between dominant and nondominant leg) values in velocity of 180º/s (P-max, $r=-0.52$ and P-10s, $r=-0.52$, $p<0.05$). The effectual cadence value (cadence where highest power was achieved) had no significant relationship with neither absolute and relative peak torque values, but was significantly related to strength maintaining rate (group average 78.3±5.4%) in hip extensors between velocities 60º/s and 180º/s (P-max, $r=0.65$ and P-10s, $r=0.54$, $p<0.05$).

Table 3. *Correlations between peak torque and cycling power (n = 17).*

		Correlations between absolute torque and absolute power values		Correlations between relative torque and relative power values	
Muscle group	**Velocity**	**P-max**	**P-10s**	**P-max**	**P-10s**
	60°/s	0.77**	0.74**	0.56*	0.47
Ankel Plantarflexors	180°/s	0.63**	0.64**	0.23	0.17
	240°/s	0.77**	0.73**	0.51*	0.35
	60°/s	0.57*	0.53*	0.30	0.22
Ankel Dorsiflexors	180°/s	0.50*	0.54*	0.14	0.17
	240°/s	0.65**	0.60*	0.23	0.04
	60°/s	0.69**	0.74**	0.52*	0.64**
Knee Extensors	180°/s	0.69**	0.69**	0.61*	0.66**
	240°/s	0.72**	0.72**	0.63**	0.67**
	60°/s	0.67**	0.79**	0.34	0.53*
Knee Flexors	180°/s	0.64**	0.65**	0.46	0.49*
	240°/s	0.67**	0.71**	0.46	0.51*
	60°/s	0.81**	0.88**	0.63**	0.72**
Hip Extensors	180°/s	0.87**	0.90**	0.72**	0.74**
	240°/s	0.86**	0.87**	0.71**	0.70**
	60°/s	0.40	0.49*	0.04	0.21
Hip Flexors	180°/s	0.43	0.42	0.12	0.13
	240°/s	0.50*	0.48	0.32	0.35

**p<0.05, **p<0.01.*

Comparison of relative strength values between higher relative power (n = 6) and lower relative power (n = 6) cyclists groups are expressed in Table 4. Faster cyclists had significantly higher relative strength level of knee and hip extensors in all tested velocities (p<0.05). The values of relative strength in other muscle groups did not have any differences between faster and slower cyclists (p>0.05). But lower power group cyclists had larger (p=0.01) knee extensors peak torque contralateral deficit values in velocity 240º/s (group average 10.2±5.0%)than higher power group members (3.2 ±2.4%).

Table 4. *Comparison of relative strength values between higher relative power (n = 6) and lower relative power (n = 6) showed cyclists based on relative 10 seconds cycling power.*

Muscle group	Velocity	Lowest relative power group (n=6)	Highest relative power group (n=6)	T-test
	60°/s	1.36±0.19	1.54±0.23	0.09
Ankel Plantarflexors	180°/s	0.94±0.16	0.94±0.17	0.48
	240°/s	0.85±0.19	0.92±0.10	0.24
	60°/s	0.36±0.04	0.38±0.08	0.24
Ankel Dorsiflexors	180°/s	0.36±0.06	0.36±0.08	0.45
	240°/s	0.36±0.08	0.32±0.05	0.17
	60°/s	2.78±0.39	3.31±0.38	0.02
Knee Extensors	180°/s	1.98±0.27	2.35±0.21	0.01
	240°/s	1.68±0.19	2.02±0.22	0.01
	60°/s	1.61±0.21	1.78±0.30	0.15
Knee Flexors	180°/s	1.21±0.18	1.33±0.12	0.11
	240°/s	1.06±0.16	1.18±0.13	0.08
	60°/s	3.92±0.63	4.71±0.71	0.03
Hip Extensors	180°/s	3.05±0.57	3.61±0.3	0.03
	240°/s	2.77±0.41	3.17±0.14	0.02
	60°/s	2.28±0.27	2.18±0.55	0.35
Hip Flexors	180°/s	1.73±0.19	1.69±0.3	0.38
	240°/s	1.49±0.17	1.56±0.31	0.31

**p<0.05*

DISCUSSION

The subjects of present study demonstrated similar effectual cadence values (group average P-max 117.1±11.7 and P-10s 112.8±10.7 rpm) with previous results of Zoladz et al. (2000) – they found that healthy physically active males have higher 10 s sprint power values in pedalling rates of 100 rpm and 120 rpm. Our results also support that most effectual cadence to achieve short term cycling power is near to 120 rpm (Van Soest & Casius 2000). It was found that effectual cadence value had no significant relations with neither absolute and relative peak torque values, but had significant relationship with strength maintaining rate in hip extensors between velocities 60°/s and 180°/s (P-max, r=0.65 and P-10s, r=0.54, $p<0.05$). Assuming that greatest torque at high velocities is related to fast twitch fibres and the number of fibres in series (Wickiewicz et al., 1984) and that cycling cadence is related also with muscle fiber architecture (Ahlquist et al., 1992; Hansen et al., 2002; Umberger et al., 2006) we can suppose that muscle architecture of main hip extensor muscles is determining the effectual cadence value.

The comparison of isokinetic strength values between different lower body muscles suggest that strongest muscle group of road cyclists are hip extensors (average body mass corrected values 4.24±0.68, 3.31±0.46 and 2.95±0.33 Nm/kg in angular velocities 60°/s 180°/s and 240°/s respectively), followed by knee extensors (3.00±0.41, 2.13±0.30 and1.83±0.25). Comparing our results with studies utilising similar methods and published by Dowson et al. (1998) we can confirm that cyclists knee extensors strength is lower than in sprint runners and rugby players (3.23 ± 0.43 Nm/kg at 60°/s and 2.06 ± 0.26 Nm/kg at 240°/s), but hip extensors strength is significantly higher (2.92 ± 0.45 at 60°/s and 2.82 ± 0.49 at 180°/s). Earlier results of the relationship between isokinetic strength at 180°/s and sprinting power of non-cycling sportsmen also found that knee extensors and flexors are more strongly correlated with cycling anaerobic power than strength of hip extensors (Smith, 1987). Our findings suggest that hip extensors torque at 180°/s have significantly more strongly related (r=0.9 between absolute values and r=0.74 between relative values) with short term cycling power compared to any other muscle group actions. Interestingly hip flexors do not have significant relationship with relative sprinting power. One explanation for differences between cyclists and non-cyclist may be the adaption of extremely low upper body position and closed hip angles of competitive cyclists. The higher strength level and stronger relationship with cycling power support findings of Martin and Brown (2009) that in maximal cycling larger portion of power is generated by hip extensors, that produce nearly twice the power of knee extension.

The importance of hip and knee extensors strength in cycling power generating ability was confirmed by correlation analysis between body mass corrected strength and power values and also by comparison of powerful and less powerful cyclists.

We fund that strength of knee flexor and hip extensor muscle groups at 60°/s in lower velocities had significantly stronger relationship with longer power production than with short time power peak. Also knee flexors had significant correlations with relative strength and power values only at P-10s while ankle plantar flexors were reversely related only with P-max values. These findings are in line with findings of Martin and Brown (2009) who showed that during the sprinting ankle joint power decreases more and rapidly than power at other lower limb joints, while hip extensors and knee flexors sustain their power for longer time at higher rate.

CONCLUSIONS

We found that the strongest muscle group in high level road cyclists are hip extensors, sprinting power has strongest relationship with hip extensors strength in angular speed 180º/s and there is no significant relationship with strength of hip flexors.

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