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Sprint cycling performance and asymmetry

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ABSTRACT

Rannama, I., Port, K., Bazanov, B., & Pedak, K. (2015). Sprint cycling performance and asymmetry. *J. Hum. Sport Exerc., 9*(Proc1), pp.S247-S258. The purpose of this study was to examine the asymmetries in cyclist's lower limbs strength and in the pedalling kinematics during a seated sprinting test and to identify the relationships between asymmetries and maximal cycling power. 16 competitive road cyclists (20.6±3.7 yrs., 181.5±5.0 cm, 74.8±7.0 kg) performed 10 Sec isokinetic maximum power test with cadence 120 RPM. The asymmetry of kinematic patterns of cyclist's upper and lower body during pedalling was registered. Separately isokinetic peak torque (PT) of main lover limbs joint were measured at angular speeds 60, 180 and 240□/s. The differences in kinematic patterns and isokinetic PT values between two limbs were analysed for descriptive and inferential statistics (relative share in %, correlations and regression between asymmetry values and cycling power). Conclusion: The highest asymmetries were found in cyclist's upper body kinematics and at the same time the most symmetrical were knee extensors strength values, but both parameters were negatively and significantly correlated with the performance of sprint cycling. By combining the leg extensors muscular strength with asymmetry of knee extensors strength and trunk kinematics the explanatory power of multiple regressions increased markedly from 0.68 to 0.92. **Key words**: PEAK TORQUE, ISOKINETIC DYNAMOMETRY, CYCLING KINEMATIC, STRENGTH ASYMMETRY.

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INTRODUCTION

Bicycling is a cyclic activity that requires in the competition situations a precise pedalling technique to maximize power application to the pedals with minimal energy cost. Although the cycling assumed to be an endurance sport, the ability to achieve a high maximum power during a short period of time is an important component of success in road cycling competitions (Ebert et al., 2006; Jeukendrup et al., 2000). Maximal cycling power output largely depends on external factors like bicycle set up (Gonzalez and Hull, 1989; Too, 1990; Rankin and Neptune, 2010; Vrints et al., 2011; Yoshihuku & Herzog, 1990), pedalling cadence (Zoladz et al., 2000; Van Soest & Casius, 2000; Dorel et al., 2005; Gardner et al., 2007; Busko, 2005), cyclists position on the bike (Bertucci et al., 2008). Also internal factors like lower limbs muscle strength (Alemdaroglu, 2012; Arslan, 2005; Rannama et al., 2013; Sanding et al., 2008; Smith, 1987), muscle coordination patterns (Blake et al., 2012) and fatigue (Martin & Brown, 2009; O'Bryan et al. 2014) play important role for achieving high pedalling power. In most of studies, analysing maximal power output in cycling, assuming that cyclists are pedalling symmetrically (Carpes et al., 2010).

Number of studies have found a notable asymmetry in the bilateral kinetics patterns of the pedalling like a crank torque (Carpes et al., 2007; Bini & Hume, 2014), different pedal force components (Daly & Cavanagh, 1976; Sanderson et al., 1991; Smak et al., 1999) and pedal power output (Smak et al., 1999). Also some studies have found asymmetry in lower limbs joint kinematics and kinetics patterns (Smak et al., 1999; Edeline et al., 2004) and muscle activation (Carpes et al., 2011), but it is noted that pedalling kinetics asymmetry may not be related to bilateral differences in the muscle activation magnitude and its variability (Carpes et al., 2010). Edeline et al. (2004) demonstrated that even with a symmetrical pedal force production existing bilateral difference in the pedalling kinematics leads to the asymmetry in joint torques and muscle loads. This indicates that bilateral differences in the kinematics may be most sensitive measures of asymmetry.

It is reported that the pedalling cadence (Liu & Jensen, 2012; Daly & Cavanagh, 1976; Fregly & Zajac, 1996; Smak et al., 1999), external workload (Edeline et al., 2004; Carpes et al., 2007b; Sanderson et al., 1991) and fatigue (Carpes et al., 2007a) have an influence on bilateral asymmetry. It seems that increase of the effort, due to higher power output or accumulated fatigue, improves the pedaling symmetry of the crank torque production (Carpes et al., 2007; Sanderson et al., 1991), but there are also opposing findings (Bini & Hume, 2014). Carpes et al. (2010) conclude that asymmetries often disappear when cycling task is performed at maximal effort. The influence of pedaling speed to the asymmetry have individual variations within subjects in the cadence range between 60 and 90 rpm, but there is a trend of increasing asymmetry in higher and very low cadences (less than 60), especially in non-cyclists population (Liu & Jensen, 2012; Smak et al., 1999).

The influence of the bilateral asymmetry on the cycling performance is not clear, but there are some findings of the relationship between the performance measures and the asymmetry from other cyclical and/or bilaterally equal motions. Yoshioka et al. (2010) examined the effect of 10% bilateral asymmetries of the muscle strength on countermovement jump performance by computer simulation and found only 0.7% difference in jump height. The experimental results of Bailey et al. (2013) indicate that force production asymmetry is negatively related to the bilateral vertical jumping performance and unlike the simulation study, in the real conditions the weaker leg may not be adequately compensated by the stronger leg.

In cyclical movements, where human body is connected with symmetrical equipment, it has been found that asymmetrical lower limb kinematics are negatively related with ergometer rowing performance (Buckeridge et al., 2012; Bull & McGregor, 2000) and the kinematics of the rowers of higher competitive level (Buckeridge et al., 2012) and kayakers (Limonta et al., 2010) were bilaterally more symmetrical.

The literature on the relationships between various asymmetries and cycling sprinting performance is extremely limited. There is a lack of information how the asymmetries in the muscle strength are related with the movement kinematic and how the asymmetrical pedalling movements are affecting the power production during maximal cycling effort.

The purpose of this study was to examine the asymmetries in cyclist's lower limbs strength and in the pedalling kinematics during a seated sprinting test and to identify the relationships between asymmetries and maximal cycling power.

MATERIAL AND METHODS

Participants

The study participants were 16 competitive male road cyclists. The participants went through anthropometrical measurements (age 20.6±3.7 yrs., height 181.5±5.0 cm and body weight 74.8±7.0 kg), completed a health screening questionnaire and signed an informed consent term in accordance with the principles of the Declaration of Helsinki. All cyclists were right-leg dominant, had at least 6 years focused cycling training and competition experience and last the season's cycling total distance was over the 15000 km. The participants, had no general (done without bicycle) strength training history during the last 6 month and were free of injuries

Instrumentation and procedures

Experimental protocol consisted of 2 separate phases: cycling sprint power tests in 3 cadence conditions with 3D kinematic video recording of cyclist's movement and isokinetic strength testing of six lower limb muscle groups in 3 angular velocity conditions.

Both experimental phases were performed during the same day. Each subject completed at first cycling tests. After 20-30 minutes of free pedalling and passive recovery after which they went through the isokinetic strength testing. The experimental phase was performed at 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 a 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). For the testing the three target cadences were set of 100 rpm, 120rpm and 140 rpm accordingly, that covers the effectual cadence area for generating maximal power (Dorel et al. 2005; Gardner et al. 2007, Zoladz et al. 2000, Van Soest & Casius 2000). All tests were conducted in sitting position hands on the drops.

Pedalling kinematics. In order to measure the pedalling movement kinematic the modified marker set of a reduced number of external markers offered by Rodano, R. et al (1996) was used. Reflective markers were attached bilaterally on the cyclists anatomical reference points (Figure 1): ankle (lateral malleoli), knee (lateral epicondyle of the femur), hip (great trochanter), pelvis (iliac crest), shoulder (greater tubercle), elbow and wrist. Additional markers were placed on the lateral side of the pedal spindles and front and rear axles of bicycle. Diameter of the passive retro reflective markers was 12 mm.

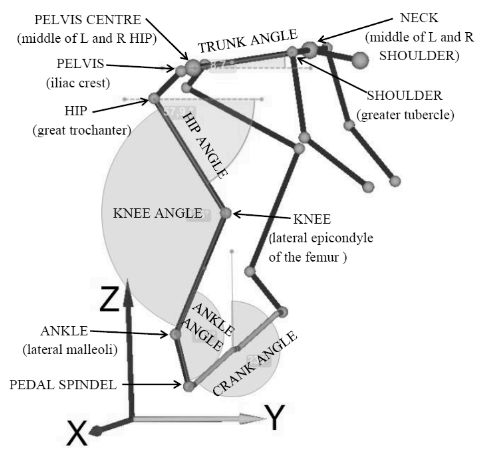

Figure 1. Anatomical reference point's and measured kinematical parameters.

All the cycling sprints were simultaneously recorded on a server using five Panasonic NV-GS230 DV cameras operating at 50 Hz and equipped with lights near to cameras lens. The cameras were mounted on the walls around the cyclists, zoomed so that the athlete was visible at maximal amount and connected with the FireWire cables to the computer. The movement space around the cycling ergometer was calibrated with 500x1000x1500 mm (X, Y and Z axis respectively) calibration matric, so that line between front and rear axles of bicycle was in the same direction with the longitudinal axis of global frame.

Video files were synchronised by led light and software Gen-Loc using Kwon-3D biomechanical analysis software (Visol, Korea). 19-segment (Figure 1) model of the cyclists were semi-automatically digitized in each image of the trials. The digitized images were interpolated to 200 Hz using 3-order spline function and the 3-dimensional coordinates of the body landmarks were calculated using the direct linear transform (DLT) algorithm. Coordinate data were smoothed using a second-order Butterworth low pass digital filter with cut-off frequencies of 10 Hz. Linear and angular positions, velocities and accelerations were computed from smoothed 3D coordinate data. Also secondary points were calculated with general mid-point method: Pelvic Centre (mid-point of Left & Right Pelvis) and Neck (mid-point of Left & Right Shoulder).

Kinematic data were interpolated with 3-order spline function from time scale to pedaling cycle scale (360º) – starting from 0 degree, when right crank is in upper position. 8 pedaling cycles between 1st and 6th second of sprint test were averaged to 1cycle. Average cycle values of computed parameters were included to the future analysis.

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 (*PF*), ankle dorsal flexors (*DF*), knee and hip extensors (*EX*) and flexors (*FL*) 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 240˚/s. At each test velocity, the subject performed 4 submaximal warm-up trials followed by 5 (60 and 180 ˚/s) or 15 (240˚/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

Cycling power test. In the cycling power test significantly higher power were achieved in cadence of 120 rpm and resulting from this the performance and kinematics of 120 rpm test were included to the future analysis. To eliminate the acceleration and fatiguing part from the 10 seconds the 5 seconds average relative power (POW5s) (W/kg) between 1-6 seconds was used as performance measure.

Pedalling kinematics. In present study only sagittal plane kinematic (around X axis) was analysed. The angles evaluated in this analysis were (Figure 1): trunk incline, hip (thigh incline), knee, ankle and bicycle crank angle. The extension and flexion angle (*AN*), angular velocity (AVe) and acceleration (*AAc*) were computed to describe every angular parameter of the right (*R*) and Left (*L*) side. To describe pelvis motion the linear displacement in Y and Z direction and absolute velocity (*Ve*) and acceleration (Ac) of pelvis centre were computed. Also the range of motion (ROM) of AN, AVe and AAc were calculated.

Isokinetic strength. 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 right and left leg were analysed as muscle group strength (expressed in Nm). The measurement of peak torque has been shown to be accurate and highly reproducible (Kannus, 1994). All strength values were normalized with the body mass (Nm/kg) and the mean values of right and left leg was used in regression modelling.

Asymmetry. The absolute values of the asymmetry were included in present study. Absolute version of the ASI proposed by Vagenas & Hoshizaki (1992) was used to assess the degree of asymmetry in PT values and was calculated using the following equation (1):

Equation 1

$$ASI = \frac{|L - R|}{max|L.R|} * 100$$

To account the time shifts and to compare the symmetries over the entire pedalling cycle and across different variables, the modified equation (2 and 3) of cycle asymmetry proposed by Nigg et al. (2013) was used:

Equation 2

$$ASI360 = \int_{c=c1}^{c360} \frac{2 * |R(t) - L(t)| \Delta c}{range(R(c)) + range(L(c))} * 100$$

where ASI360 is the asymmetry index, R(c) is the value of a specific variable recorded for the right leg at the cycle position c and L(c) the value recorded for the left leg at the cycle position c, c1 is the 1 degree position of L or R crank when pedaling cycle starts, and c360 is 360 degree position when pedaling cycle finished. The asymmetry is normalized by incorporating the range of the R(c) and L(c) variables, it makes possible to compare variables with different magnitudes as well as different units (Nigg et al. 2013).

The average ASI(%) 360 were computed from AN, AVe and AAc values for hip, knee and ankle. For calculations of the asymmetry in the pelvis and trunk kinematics the values between L and R side pushing phases (1-180º in pedalling cycle) were compared. The ASI360 for the trunk were computed similarly to the legs. Pelvis ASI360 computed as mean of Pelvis Centre position (Y and Z axis of sagittal plane), resultant linear velocity and acceleration ASI360.

Analysis
Statistical software SPSS version 21.0 (IBM company, New York) was used for data 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 asymmetry values between different joints and movements. Pearson product-moment correlation was used to examine the relationship between variables. Significance level for t-test and correlation tests was set at $p<0.05$. To examine the relationships between asymmetry variables (independent variables) and POW-5s (dependent variable), stepwise multiple linear regressions were performed. The entry significance level for independent variables was $P<0.05$, while the removal significance level was $P>0.10$.

RESULTS

The average absolute power of cycling sprint test was 1090±162W (ranged from 777 to 1322 W) and relative power (POW5s) was 14.5±1.5 (from 11.2 to 16.6 W/kg). The results of isokinetic PT and strength asymmetry, also the correlation coefficient with relative 5 seconds power are shown in Table 1.

Table 1. Descriptive data and correlations with POW-5s of relative isokinetic strength and strength asymmetry for the knee, hip and ankle joints at different velocities (n = 16)

Peak Torque (Nm/kg)	Min	Max	Mean	Std. Dev.	Correl. POW5s	Peak Torque Asymmetry	Min	Max	Mean	Std. Dev.	Correl. POW5s
Ankle PF60PT	1,06	1,72	1,43	0,22	0,38	Ankle PF60ASI	0,7	28,4	9,1	8,2	0,18
Ankle PF180PT	0,66	1,14	0,91	0,16	0,07	Ankle PF180ASI	1,5	20,4	10,2	6,6	0,32
Ankle PF240PT	0,57	1,04	0,89	0,15	0,35	Ankle PF240ASI	1,2	37,0	12,7	9,1	0,17
Ankle DF60PT	0,25	0,46	0,37	0,06	0,20	Ankle DF60ASI	0,0	32,4	11,4	8,4	0,20
Ankle DF180PT	0,22	0,51	0,37	0,08	0,10	Ankle DF180ASI	0,0	29,0	13,3	11,1	0,42

Ankle DF240PT	0,26	0,47	0,35	0,07	0,06	Ankle DF240ASI	0,0	36,6	11,1	12,4	0,24
Knee EX60PT	2,20	3,95	2,99	0,41	0.65**	Knee EX60ASI	0,6	17,2	5,8	4,3	-0,04
Knee EX180PT	1,50	2,69	2,12	0,32	0.68**	Knee EX180ASI	0,0	15,9	7,6	4,3	-0.50*
Knee EX240PT	1,34	2,37	1,81	0,26	0.74**	Knee EX240ASI	0,0	12,8	6,9	4,2	-0,25
Knee FL60PT	1,19	2,12	1,70	0,27	0.53*	Knee FL60ASI	0,0	18,3	8,2	6,1	-0,14
Knee FL180PT	0,97	1,61	1,26	0,18	0,39	Knee FL180ASI	2,7	27,9	9,9	7,4	0,08
Knee FL240PT	0,84	1,42	1,12	0,16	0,44	Knee FL240ASI	0,0	31,3	9,2	8,5	-0,07
Hip EX60PT	2,87	6,03	4,17	0,68	0.64**	Hip EX60ASI	0,0	17,9	7,5	5,3	0,43
Hip EX180PT	2,13	4,14	3,27	0,46	0.74**	Hip EX180ASI	1,8	24,6	9,5	7,6	-0,20
Hip EX240PT	2,33	3,44	2,93	0,34	0.74**	Hip EX240ASI	0,0	20,9	8,5	6,1	-0,24
Hip FL60PT	1,03	2,76	2,23	0,42	0,23	Hip FL60ASI	0,0	15,6	7,0	4,4	-0,24
Hip FL180PT	1,13	2,20	1,73	0,27	0,14	Hip FL180ASI	0,7	20,9	9,9	5,8	0,09
Hip FL240PT	1,08	2,06	1,52	0,25	0,34	Hip FL240ASI	0,8	29,6	8,5	8,4	0,22

Note*. Correlation is significant at the 0.01 level (2-tailed)*. Correlation significant at the 0.05 level (2-tailed).

Largest asymmetry was found from the strength of the muscle group crossing the ankle (significantly different (p<0.05) between hip and knee asymmetry) and less asymmetrical were knee extensors. Number of significant relationships was found between the relative cycling sprint power and isokinetic strength components. Sprint power correlated significantly with the hip and knee extensors in all velocities and the knee flexors in velocities 60°/s. It was also found that there is a negative correlation between the cyclist's power and knee extensors peak torque ASI.

Two 3-component multiple regression models with PT and PT ASI data were composed (Equations 3 and 4). Regression models including muscular strength and strength asymmetry can explain over the 80% of variation in short term cycling power. Also only the leg extensor muscle groups are involved in the models and knee extensors strength ASI affect negatively the performance. When only PT values were included in the models, then the prediction level was lower than 70% (R square 0.69 and 0.68 for models in equations 1 and 2 respectively) and with inclusion of knee PT ASI parameter the explanatory power of regression model increase significantly.

Equation 3

$$POW5s = 3.943 + 2.164 * KneeEX240PT + 2.59 * HipEX240PT - 0.134 * KneeEX240ASI$$

$$(r^2 = 0.826)$$

Equation 4

$$POW5s = 5.616 + 3.676 * KneeEX240PT + 2.133 * AnklePF60PT - 0.106 * KneeEX180ASI$$

The results of the kinematical ASI360 (Table 2) confirmed that the largest asymmetry does exist in upper body movement. There was no significant difference between pelvis and trunk ASI360 (p=0.5), but the upper body asymmetry values are significantly higher than legs ASI360 values (p<0.05). Similar to PT ASI, were ankle muscles show largest asymmetry in the kinematics of the lower limb ankle ASI360 was higher (p<0.05) than the knee and hip values. The knee and hip ASI360 did not differ significantly (p= 0.54).

The correlation analysis refers to significant negative relationships between POW5s and the upper body segments kinematical asymmetry however the inequality of legs kinematic did not correlate significantly with the sprinting power. ASI360 of the hip and knee are positively correlated and pelvis asymmetry correlates with the ankle and trunk asymmetry.

Table 2. Descriptive data of kinematical ASI360 and correlations between POW-5s and ASI360 values (n = 16)

Kinematical asymmetry	Descriptive statistics				Correlation				
	Min	Max	Mean	Std. Dev.	POW5s	Ankle-ASI(%)360	Knee-ASI(%)360	Hip-ASI(%)360	Trunk-ASI(%)180
Ankle-ASI360	4,9	18,3	9,8	4,3	-0,31				
Knee-ASI360	1,5	12,1	3,4	2,5	0,03	0,33			
Hip-ASI360	1,4	7,6	3,7	1,6	0,12	0,36	0.68**		
Trunk-ASI180	3,1	58,0	17,2	13,0	-0.65**	0,26	-0,17	-0,11	
Pelvis-ASI180	6,4	29,9	15,4	6,7	-0.63**	0.531*	-0,07	0,17	0.61*

Note** Correlation is significant at the 0.01 level (2-tailed).*. Correlation significant at the 0.05 level (2-tailed).

Two components multiple regression model (Equation 5), when combining strength and kinematical asymmetries was stronger predictor of 5 seconds power production than looking separately the asymmetry of the knee extensors strength at 180 deg/sec or the trunk angular motion ASI360. Also the prediction power of ASI model (Equation 5) was in same level with prediction power of models where only PT values were included.

Equation 5

$$POW5s = 17.071 - 0.17 * TrunkASI360 - 0.072 * KneeEX180ASI \quad (r^2 = 0.67)$$

The highest prediction level was achieved by combining the PT and asymmetry patterns in the same regression model (Equation 6), then r-square rise to 92.

Equation 6

$$POW5s = 9.224 + 2.937 * KneeEX240PT + 1.213 * AnklePF60PT - 0.122 * KneeEX180ASI \quad - 0.048 * TrunkASI360 \quad (r^2 = 0.92)$$

$$POW5s = 9.224 + 2.937 * KneeEX240PT + 1.213 * AnklePF60PT - 0.122 * KneeEX180ASI \quad - 0.048 * TrunkASI360$$

DISCUSSION

The aim of this study was to examine the asymmetries in cyclist's lower limbs strength, in the pedalling kinematics and the relationships between asymmetries and maximal cycling power. The subjects of present study demonstrated the highest asymmetry of upper body kinematics. In lower limbs were the most asymmetrical ankle joint torques and angular kinematics. Lower asymmetry of pedalling kinematics and PT values were observed from hip and knee parameters. Regarding the earlier findings that suggest enhanced symmetry in high intensity cycling (Carpes et al. 2010), shows the present study significant asymmetries in pedalling kinematics, especially in upper body and ankle kinematics. One reason of the notable asymmetry can be high pedalling cadence (120 rpm) used in our study, because high cadence is declared to be the contributing factor of asymmetry (Liu & Jensen, 2012; Smak et al., 1999). Relatively high cadence may also be the reason of large asymmetry in ankle motion. At cadence above 120 rpm relative contribution of ankle plantar flexion in pedalling power production decrease (McDaniel et al. 2014) and cadence over 100 rpm significantly increase EMG-activity of thigh muscles (Baum and Li 2003). Those results indicate compromised coordinative patterns for ankle joint that directs force to the pedal and this can increase differences between dominant and no dominant leg. Knee flexors and knee and hip extensors are main power generators in sprint cycling (Elmer et al. 2011; Martin & Brown, 2009; McDaniel et al. 2014; O'Bryan et al. 2014) and are less affected by high cadence (McDaniel et al. 2014; Baum & Li 2003). This can be reason of lower and related asymmetry in hip and knee joint kinematic and also lower asymmetries in PT values compared to ankle PT ASI.

No earlier data about upper body asymmetry in cycling are presented, but do exist findings from rowing where pelvis kinematics were influenced by asymmetrical movement of hips and knees (Buckeridge et al., 2012). In present study asymmetries of cyclist's pelvis and ankle were related, but no significant correlations were found with hip and knee movement asymmetry but at the same time existed relation between knee and hip asymmetry. Relation between ankle and pelvis asymmetrical movement need a future investigation.

The main finding of present study is remarkable negative relation between upper body asymmetry and maximum cycling power production. The asymmetry in trunk kinematic and knee EX strength at 180 deg/s with combination of knee EX and ankle PF PT can explain more than 90% from variability of sprint power production. The upper body asymmetry and its relation with cycling performance need a future investigation by including also pelvis asymmetry assessments in combination with trunk and pelvis region muscles performance.

One limitation of the present study was that force applied on the pedals and bilateral EMG of main leg muscles could not be measured. This would present whether differences in pedalling kinematics are related to differences in force production and muscular activity between legs.

CONCLUSIONS

The highest asymmetries were found in cyclist's upper body kinematics and at the same time the most symmetrical were knee extensors strength values, but both parameters were negatively and significantly correlated with the performance of sprint cycling. By combining the leg extensors muscular strength with asymmetry of knee extensors strength and trunk kinematics the explanatory power of multiple regressions increased markedly from 0.68 to 0.92.

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