ORIGINAL RESEARCH PAPER

BILATERAL BIOMECHANICAL ASYMMETRY DURING 30 SECONDS ISOKINETIC SPRINT-CYCLING EXERCISE

Indrek Rannama, Kristjan Port

Institute of Health Sciences and Sport, Tallinn University, Estonia
Corresponding author: Indrek Rannama
Adress: Räägu 49, 11311 Tallinn, Estonia
Phone: +372 5141077
E-mail: rannama@tlu.ee

Abstract

The purpose of present study was to examine the bilateral differences of pedalling kinetics and thigh muscle activity patterns according to leg dominance during the 30 seconds maximal cycling exercise and to analyse the relationships between asymmetries of pedalling kinetics and muscle activity. Methods: The pedalling power (POW), power production smoothness (PS) and EMG of VL, RF and BF of 17 competitive cyclists (19.2±1.6y.; 1.82±0.07m; 74.1±8.2kg) were measured bilaterally during maximal 30s isokinetic (cadence limit 100 rpm) seated cycling exercise. The dynamics of POW, PS and normalized EMG-RMS amplitude and median frequency (MF) of dominant (DO) and non-dominant (ND) side were measured. The directional asymmetry indexes (AI%) between DO and ND side were computed and compared with student t-test for paired samples. Correlation analyse between AI(%) of pedalling kinetics and EMG patterns was made. Results: The DO side POW and PS values were significantly ($p<0.05$) higher than ND during the all exercise time (except POW between 5-10 sec). No significant bilateral differences were found between normalized EMG amplitude values. The AI(%) of POW and PS were significantly lowered during the exercise. Significant correlations were found between AI (%)-s of PS and VL EMG MFr ($r=-0.64$) and between AI(%)-s of POW and VL normalized EMG amplitude ($r=0.63$).Conclusions: Results of the present study indicate that during 30 seconds maximal intensity cycling does exist leg dominance dependent asymmetries in pedalling power patterns, which decreased during the exercise and was related with bilaterally asymmetry of vastus lateralis muscle firing patterns.

Key words: *Surface EMG, Pedalling Power, Leg Dominance*

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Introduction

Bicycling is a bilateral cyclical movement and for that reason in most of studies, analysing cycling biomechanics, assuming that cyclists are pedalling symmetrically and have mainly focused on measurements of only one body side (Carpes, Mota & Faria, 2010). In same time the numbers of studies have found a notable asymmetry in the bilateral biomechanical patterns of the pedalling and muscle strength values of competitive cyclists (Rannama et al., 2013; Yanci & Arcos, 2014). Earlier studies focused on recreational population and noted between-legs differences in pedalling kinetic variables like a work (Cavanagh et al., 1974) and crank peak torque (Daly & Cavanagh, 1976). Most of latest researches in this field have been focused on pedalling kinetics and have declared bilateral asymmetry in competitive cyclist's population in crank torque (Carpes et al., 2007; Bini & Hume, 2014) or different pedal force components profile (Sanderson, 1990; Smak, Neptune & Hull, 1999) and pedal power output (Smak, Neptune & Hull, 1999). Also in some studies have found asymmetry in lower limbs joint kinematics and kinetics patterns (Smak, Neptune & Hull, 1999; Rodano, Squadrone & Castagna, 1996; Edeline et al., 2004), but there have been made only a few studies about between-legs differences in muscle activation patterns (Carpes et al., 2010; Carpes et al., 2011).

There are noted differences in pedalling kinetics variables according to leg dominance, identified by kicking preference. Daly & Cavanagh (1976) stated the direction of asymmetry was unrelated of limb dominance and varied day to day. Smak, Neptune & Hull (1999) found that, at the work rate of 250 W and in cadences between 60 to 120 rpm, cyclist's dominant leg contributed significantly greater average crank power than non-dominant leg, despite the relatively small difference (0.5-2%). Same study (Smak, Neptune & Hull, 1999) also found higher average positive and negative crank powers in non-dominant side, which refers to different bilateral pedalling technique. There are also described higher crank peak torque values of dominant leg in low to submaximal powers of incremental test (Carpes et al., 2008) and in 40km long simulated time trial (Carpes et al., 2007). It seems that higher power output (Carpes et al., 2008; Sanderson et al., 1991) or accumulated fatigue (Carpes et al., 2007), as indicators of increased effort (Carpes, Mota & Faria, 2010), improve the symmetry of pedalling kinetics, but there are also opposing findings (Bini & Hume, 2014). The asymmetry of pedalling kinetics is also influenced by pedalling rate, but those relations are at the moment not fully understood (Carpes, Mota & Faria, 2010). In the cadence range between 60 and 90 rpm cyclists have individual variations in change of bilateral leg contribution (Smak, Neptune & Hull, 1999), but there is a trend of increasing absolute asymmetry in higher (over 120rpm) and very low cadences (less than 60), especially in non-cyclists population (Liu & Jensen, 2012; Smak, Neptune & Hull, 1999).

The relations between asymmetries of different biomechanical variables, such as pedalling kinetics, movement kinematics and muscles activity, are not frequently discussed. Edeline et al., (2004) demonstrated that even with a symmetrical pedal force production there was existing bilateral difference in the pedalling kinematics and this leads to the asymmetry in joint torques and muscle loads. In same line are findings of Smak, Neptune & Hull (1999) about leg dominance driven differences in knee and hip joint torque profiles. The bilateral leg dominance driven asymmetries have found in normalized EMG amplitude values of squat jump (Ball & Scurr, 2014) which is similar movement to cycling. In contrast Carpes, et al., (2010b) compared dominant and non-dominant legs normalized EMG-s of 3 muscle groups during single leg cycling at submaximal constant load intensity and found no dominance related differences. During the incremental cycling test Carpes et al., (2011) noted lower EMG variability in Biceps femoris, Gastrochnemius and Vastus lateralis muscles of dominant leg in some conditions, but no significant bilateral differences were found in normalized EMG amplitude values. To best of our knowledge no studies about relationships between bilateral asymmetry of pedalling kinetics and muscle activity of leg muscles are presented.

Competitive road cycling requires for success not only good endurance, but also ability to produce high level maximum power during a short period of time (Ebert et al., 2006; Jeukendrup, Craig & Hawley, 2000). Above discussed researches looked asymmetry in submaximal and mainly in aerobic exercise conditions, but there is lack of known about between-legs differences in pedalling biomechanics and muscle activity patterns during short term maximum anaerobic performance. It is known that during submaximal cycling dominating muscles are knee extensors (Broker & Gregor, 1994; Ericson, 1988) but in maximal cycling condition larger portion of power is generated by hip extensors that produced nearly twice the power compared to knee extension (Martin & Brown, 2009). Also relatively less knee extension and more knee flexion power will be produced (Elmer et al., 2011). The relative larger increase (5 – 9 times) of hip flexors and extensors and knee flexors muscle activity have been found with power increase from 150W to maximum, whereas ankle plantar flexors and knee extensors activity increased only 2-3 times (Dorel, Guilhem, Couturier & Hug, 2012).

During 30 seconds maximal cycling trial the fatigue occurred at different rates – the hip extensors sustain their power longer and at higher rate, while ankle joint power tends to decrease most rapidly compared to other lower limb joints and in knee joint the flexors power decline is lower than in extensors (Martin & Brown, 2009). On sEMG values reported significant decline in median frequency of the power spectrum of ankle plantar flexors and knee extensors (averagely 14-19%), but sEMG amplitude values are significantly reduced only in plantar flexors and not in knee extensors (Greer et al., 2006; Hunter et al., 2003). There is a lack of evidence about role of laterality and existence of bilateral differences in muscle fatiguing during anaerobic single-sprint exercise.

The purpose of present study was to examine the bilateral differences of pedalling kinetics and thigh muscle activity patterns according to leg dominance during the 30 seconds maximal cycling exercise and analyse the relationships between asymmetries of pedalling kinetics and muscle activity.

Material and methods

Participants. The study participants were 17 competitive U23 class male road cyclists of age ranging from 18 to 22 (21.1±3.5years, 181.5±5.0cm, 74.8±7.0kg). All athletes had at least 6 years focused endurance cycling training and competition experience. 16 cyclists were right leg dominant and one was left leg dominant, identified by kicking preference (Smak et al., 1999).

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 after the end of competitive season and before the start of new preparation period for cyclists.

Procedures

Experimental cycling exercise 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. Exercise protocol consisted 4 stages: 10 minutes warm-up of steady ride in power level up to 150W, 6 seconds of isokinetic maximal sprint with cadence set in 100rpm for EMG amplitude normalization, 25 – 30 minutes warm up with mixed power up to VO2 max level to and 30 seconds maximal isokinetic sprint performance with limited cadence set in 100rpm. All experimental cycling tests were conducted in sitting position hands on the drops.

For measurement of *pedalling kinetic*s bicycle of each participant equipped with same pair of Garmin Vector power meter pedals (Garmin Vector™). Vector pedals were installed and calibrated before each testing session according to description of manufacturer guidelines.

Muscle activity data were recorded bilaterally by surface electromyography (sEMG) from three tight muscles: the *long head of biceps femoris* (BF), the *rectus femoris* (RF) and the *vastus lateralis* (VL) muscles. These muscles were chosen because they are dominant muscles from tree different muscle synergy group involved in cycling (Hug, Turpin, Guevel & Dorel, 2010). Due to technical problems with one sEMG probe during the experimental time only 9 persons sEMG of BF were included to future analysis.

The skin of participants was shaved and cleaned with alcohol to improve the skin impedance. A pair of Ag/AgCl electrodes with inter-electrodes distance of 30 mm was applied on each muscle symmetrically for dominant (DO) and non-dominant (ND) limb, following the SENIAM recommendations (Hermens et al., 2000). Always the same person attached all the electrodes. A wireless electromyography BTS FreeEMG 300 measurement system (BTS, Inc., Milan, Italy) was used to collect sEMG data from six bipolar wireless probes (8.5g). The system features an A/D converter within an EMG sensor for eliminating external noises. Six sEMG channels and one pedal position and start triggering switch channel sampled at 1000 Hz frequency.

The sEMG signal was synchronized with pedalling cycle kinematics by magnetic switch positioned in bottom dead centre of left crank and with cycle ergometer and power pedals by start switch.

Measures. The kinetics of pedalling are described by pedalling power (POW) and pedalling smoothness (PS=pedalling cycle Average power/Maximum power*100(%)) collected from Garmin Vector pedals with 1 seconds interval separately from DO and ND side from start to end of experimental exercise. The muscle activity patterns were normalized RMS EMG (%) and EMG median frequency (MFr). For all patterns average values of 30 seconds and six (from 0 to 5; 5 to 10; 10 to 15; 15 to 20; 20 to 25 and 25 to 30 seconds) consecutives 5 seconds long time periods were taken to future analyse. Measurements and initial analysis of values were expressed as a mean of dominant and nondominant leg.

The directional asymmetry index (AI(%)=100*(DO-ND)/0.5*(DO+ND)) was calculated (Robinson, Herzog & Nigg, 1987) for pedalling kinetic and sEMG variables.

Analysis

The stored sEMG data were analysed with BTS SEMGAnalyzer (BTS, Inc., Milan, Italy) with custom made analyse protocols. Raw EMG signals of 6 seconds normalization and 30 seconds experimental trail were high-pass filtered (10Hz, Butterworth filter) to eliminate possible external noises. To compare the bilateral muscle firing rate patterns and fatigue accumulation during the exercise the median frequency (MFr) values of sEMG power spectrums of whole test and six consecutive 5 seconds time periods were computed. Filtered sEMG signals of normalization and experimental trial were root mean squared (RMS) with 0.025 seconds moving time window to make linear envelope of sEMG amplitude. The sEMG amplitude normalization was made by peak amplitude method according to the directions of Ball and Scurr (2013). Highest 0.025 second RMS value of 6 seconds normalization sprint for each muscle for DO and ND side were taken for normalization of RMS values of experimental trail. Average normalized sEMG RMS amplitude values of whole exercise and every 5 seconds time period were computed and incorporated to the future analyse.

Data analyses were performed using the IBM SPSS Statistics version 21.0 for Windows. Descriptive data were computed for all variables and all time period and 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 values of DO and ND leg and changes between time periods. The correlation analyze between AI(%) of pedaling kinetic and sEMG values were made. Significance level was set at $p<0.05$ for all analyses.

Results

The average absolute power of 30 seconds cycling sprint test was 846±115 W (ranged from 592 to 1124 W) and relative power was 11.4±1.0 W/kg (from 9.6 to 13.3 W/kg). The descriptive statistics of pedalling kinetics, EMG amplitude and frequency results and between DO and ND side asymmetry values are presented in Table 1. The dynamics of named variables during the test within 5 seconds time stages are presented in figures 1-4.

Table 1

The descriptive statistics of pedalling kinetics, EMG amplitude and frequency values of DO and ND leg, AI (%) and paired t-test results between bilateral values of 30 seconds maximal cycling exercise

		N	Mean	Std. Dev	AI (%)		Paired t-test Sig. (2-tailed)
					Mean	Std. Dev	
PS	DO	17	34.5	2.9	8.74	4.57	0.00*
	ND	17	31.6	2.7			
POW	DO	17	430.8	60.7	3.43	4.27	0.00*
	ND	17	415.5	56.0			
RF RMS	DO	17	18.3	4.9	-8.92	26.46	0.17
	ND	17	20.0	5.1			
VL RMS	DO	17	22.2	4.7	10.04	28.21	0.17
	ND	17	20.1	4.1			
BF RMS	DO	9	22.1	3.9	9.08	23.38	0.22
	ND	9	20.1	3.1			
RF MFr	DO	17	79.0	7.8	3.60	8.95	0.09
	ND	17	76.0	6.3			
VL MFr	DO	17	65.0	7.2	-1.99	14.98	0.55
	ND	17	66.4	6.6			
BF MFr	DO	9	68.5	10.5	-5.52	9.53	0.01*
	ND	9	73.6	9.1			

*- significant differece between DO and ND side ($p<0.05$)

The comparison of 30 seconds DO and ND leg average values (Tab.1) refers to significantly ($p<0.05$) higher PS and POW of DO side and higher MFr values of BF muscle. This trend is also shown in dynamics of named variables during the exercise (figures 1 and 2), where PS and POW bilateral differences are maintained from start to end part, but BF MFr differences are disappearing during the last 10 seconds of the exercise.

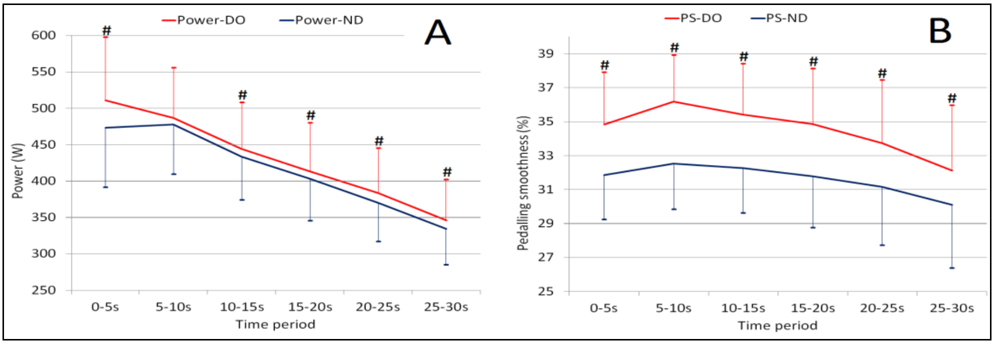

Figure 1. Dynamics of average (+/-SD) DO and ND side pedalling power (POW) (Figure 1A) and pedalling smoothness (PS)(Figure 1B) values observed within the 5 seconds time periods of exercise (n=17)

(#- significant differece between DO and ND side $p<0.05$)

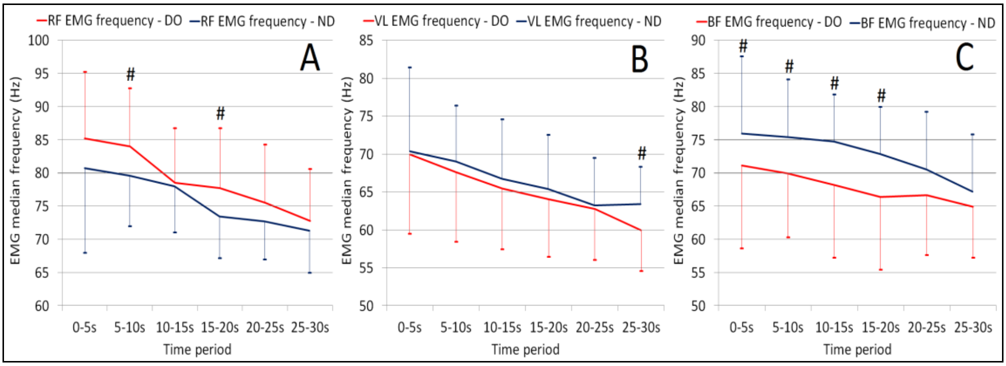

Figure 2. Dynamics of average (+/-SD) DO and ND leg sEMG firing rate values observed as median frequencie of 5 seconds time periods for *Rectus femoris* (RF) (Figure 2A), *Vastus Lateralis* (VL) (Figure 2B) and *Biceps femoris long head* (BF) (Figure 2C) muscles (n=17; n=9 for BF)
(#- significant differece between DO and ND side p<0.05)

There does exist also some significant differences between DO and ND leg for RF MFr in middle – and for VL MFr in end part ot the exercise. No significant bilateral differences were found between normalized EMG amplitude values of any muscle at any stage of exercise.

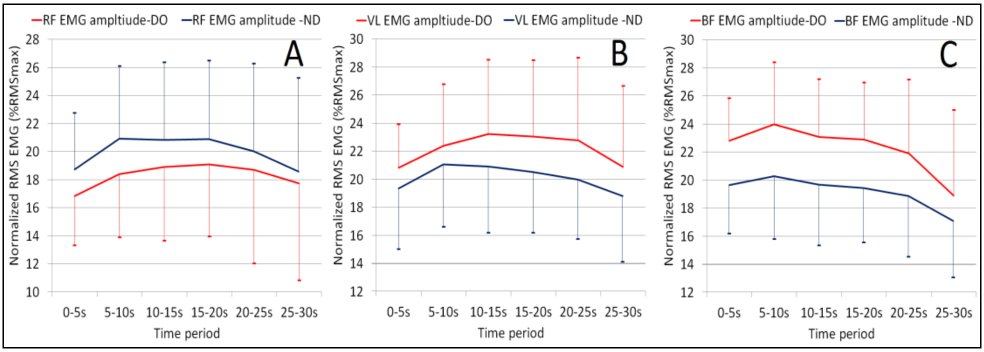

Figure 3. Dynamics of average (+/-SD) DO and ND leg normalized sEMG amplitude values observed within 5 seconds time periods for *Rectus femoris* (RF) (Figure 3A), *Vastus Lateralis* (VL) (Figure 3B) and *Biceps femoris long head* (BF) (Figure 3C) muscles (n=17; n=9 for BF)
(#- significant differece between DO and ND side p<0.05)

The AI(%) value of POW was higher (7.7 ±8.4%) at initial part of exercise and after 5 seconds lowered significantly (to the level between 1.9±4.1 and 3.2± 6.3%), PS AI(%) had also significantly higher values in first 10 than in last 10 seconds of effort (Figure 4A). The EMG AI(%)

variables (Figure 4 B andC) have opposite directions in firing rate and amplitude patterns and amount of AI(%) of RF and BF do have the trend to decrease, but VL AI(%) has the trend to increase in the final stage of exercise.

The comparison between initial 5 and last 5 seconds values shows that pedalling kinetics (POW, PS) and EMG frequency decrease significantly during the test. For EMG amplitude there was only significant difference between DO BF start and end part values. But there does exist significant differences between second stage (5-10 sec) and final stage DO and ND BF normalized RMS EMG and between third stage (10-15 sec) and final stage DO and ND VL normalized RMS EMG values.

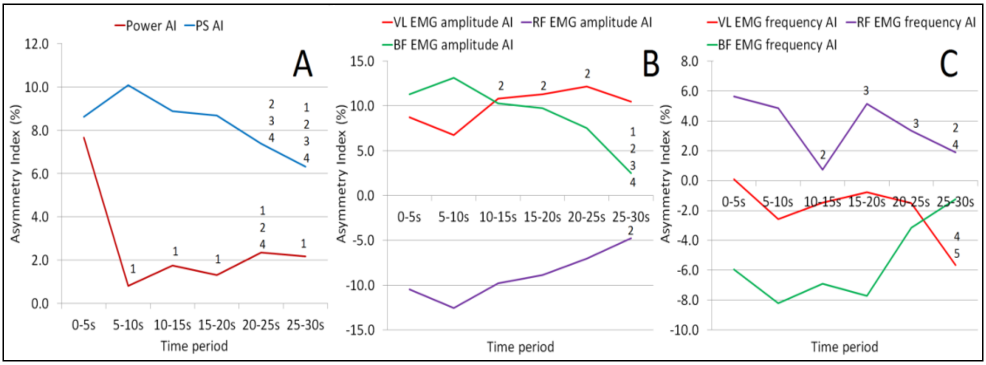

Figure 4. Dynamics of average AI(%) of pedalling kinetic (Figure 4A), normalized sEMG RMS amplitude (Figure 4B) and sEMG MFr (Figure 4C) values observed within the 5 seconds time periods of exercise (n=17)

(1-significantely different from 1-st time period; 2 - from 2-nd period; 3 - from 3-nd period; 4 - from 4-th period; 5 - from 5-th period, p<0.05)

Table 2

Correlations between computed 30 seconds average AI (%) values of pedalling kinetics and muscle activity variables

AI (%) of kinetics	PS							
	Pow	.533*						
AI (%) of EMG RMS	RF	0.07	0.02					
	VL	0.38	.626**	0.21				
	BF	0.24	0.27	0.41	0.22			
AI (%) EMG MFr	RF	-0.08	-0.24	-0.30	-0.47	-.749*		
	VL	-.639**	-0.16	-0.23	-0.30	0.07	-0.02	
	BF	0.09	0.44	.845**	0.47	0.47	-0.30	0.00

* Correlation is significant at the p<0.05 level (2-tailed).

** Correlation is significant at the p<0.01 level (2-tailed)

Table 3

Correlations between computed 30 seconds average AI (%) values of pedalling kinetics and muscle activity variables

		AI (%) of Pedalling Smoothness						AI(%) of Power					
		0-5s	5-10s	10-15s	15-20s	20-25s	25-30s	0-5s	5-10s	10-15s	15-20s	20-25s	25-30s
AI (%) of Power		.374	.203	.558*	.594*	.571*	.417	1	1	1	1	1	1
AI (%) of EMG RMS	RF	-.194	-.209	.169	.075	.269	.519*	-.222	.266	.116	.284	-.008	.192
	VL	.412	.165	.324	.532*	.420	.340	.197	.589*	.674**	.652**	.605*	.607**
	BF	.305	.238	-.021	-.062	.266	.398	-.188	.273	.472	.350	.335	.353
AI (%) of EMG MFr	RF	-.025	-.013	.234	-.072	-.112	-.352	-.046	-.287	-.125	-.099	-.180	-.080
	VL	-.459	-.285	-.633**	-.746**	-.504*	-.375	.367	-.192	-.259	-.212	-.284	-.117
	BF	.112	.136	.297	.233	-.183	-.112	.088	.627	.545	.542	.097	.295

* Correlation is significant at the p<0.05 level (2-tailed).

** Correlation is significant at the p<0.01 level (2-tailed)

The correlation analyse results are presented in Tables 2 and 3. Significant correlations were found between AI (%)-s of PS and VL EMG MFr and between AI (%)-s of POW and VL normalized EMG amplitude. If to look correlations according to time periods, than stronger relations were found during the middle part of exercise and no significant correlations were found between initial stage values. Also the PS AI (%) and POW AI (%) values are significantly correlated only in between 10 to 25 seconds of exercise.

Discussion

The one purpose of present study was to examine the bilateral differences of pedalling kinetics and thigh muscle activity patterns according to leg dominance during the 30 seconds maximal cycling exercise. With accordance of previous studies, done mainly in aerobic exercise conditions (Smak, Neptune & Hull, 1999; Carpes et al., 2007; Carpes et al., 2008), our results suggest that exist also leg dominance driven asymmetry in pedalling kinetic patterns during the maximal short term cycling. During the maximal cycling DO limb produces higher power with more equally over the pedalling cycle, which is in line with findings of Smak, Neptune & Hull (1999), that dominant leg generate higher average pedalling power with lower average positive and negative power production than ND limb.

Higher between legs bilateral differences were found during initial 5 seconds power and first 10 seconds pedalling smoothness values. After that power asymmetry dropped significantly and stayed almost in same level till the end of exercise. PS asymmetry and also pedal smoothness of DO and

ND side lowered gradually and significantly and had lowest values in final 5 seconds. It seems that asymmetry of pedalling power production during short duration maximal exercise is more sensitive to fatigue like long time trial performance (Carpes et al., 2007), but not to the high power because asymmetry of power production was larger in acceleration part at start of exercise, when the power was higher.

Previous studies about comparison of DO and ND legs normalized sEMG amplitude values did not found any dominance related differences in incremental or single leg constant load intensity cycling (Carpes et al., 2010; Carpes et al., 2011). The results of present experiment showed that there were no significant dominance related differences between DO and ND side normalized EMG RMS values of RF, VL, BF muscles at any time period of exercise.

To the best of our knowledge no previous studies have done to compare sEMG firing rate patterns between DO and ND thight muscles during cycling exercise. Our data indicated that there exist some significant bilateral leg dominance driven differences in BF MFr values during the initial 20 seconds of exercise and those differences expiring in the end part of exercise. Also were found bilateral differences in some time stages of VL and RF MFr values. It is known that motor units firing frequency modulation become predominant over motor units recruitment mechanism when moderate or high force level is required (Moritani & Yoshitake 1998) and that sEMG firing rate is more sensitive to fatigue than firing amplitude during short term anaerobic exertion (Greer et al., 2006; Hunter et al., 2003). From that view the future investigation of asymmetrical EMG frequency patterns may have important role for understanding neurological mechanisms of pedalling asymmetry.

The pedalling kinetics asymmetry was significantly correlated with asymmetry of VL EMG patterns. Larger DO side PS were associated with higher VL MFr values in ND side and higher DO side asymmetry in POW values was related with same direction asymmetry in VL normalized RMS amplitude. The relationship of VL muscle activity regarding to cycling intensity is well known (Moritani & Yoshitake 1998; Berice et al., 2009) and our findings suggest that between-legs differences in VL EMG amplitude and firing rate may play significant role in directional asymmetry of pedalling kinetics. For better understanding of mechanisms behind cycling asymmetry in future research in the analysis should be incorporated also pedalling kinematic and cyclist’s musculoskeletal state values.

Conclusions

Results of the present study indicate that during 30 seconds maximal intensity cycling do exist leg dominance dependent asymmetries in pedalling power patterns, which decreased during the exercise and were related to bilaterally asymmetry of *vastus lateralis* muscle firing patterns.

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