ORIGINAL RESEARCH PAPER

PEDALLING TECHNIQUE AND POSTURAL STABILITY DURING INCREMENTAL CYCLING EXERCISE – RELATIONSHIP WITH CYCLIST FMS^{TM} SCORE

Indrek Rannama, Kirsti Pedak, Karmen Reinpõld, Kristjan Port

School of Natural Sciences and Health, Tallinn University, Estonia
Corresponding author: Indrek Rannama
Adress: Räägu 49, 11311 Tallinn, Estonia
Phone: +372 6996544
E-mail: rannama@tlu.ee

Abstract

Purpose of the present study was to examine the changes in the pedalling kinetics and in the ground reaction forces as a measure of the cycling stability during an incremental cycling exercise. Furthermore, we compared the effectiveness of the pedalling technique and postural stability between the high and low Functional Movement Screen score (FMS^{TM}) cyclists and analysed the relationships between the cycling specific postural stability, pedalling kinetics and cyclists FMS^{TM} test scores. 31 competitive cyclists (18.5±2.1y; 1.81±0.06m; 73.7±7.5kg) were categorized based on the (FMS^{TM}) test results in a low (LS, n=19; FMS≤14) and a high (HS, n=12; FMS>14) score group. The pedalling effectiveness and absolute symmetry indexes, as well the ground reaction force (GRF) were measured during incremental cycling exercise. Cycling specific postural stability was expressed as the body mass corrected standard deviation of 3 linear and 3 angular GRF components during a 30sec cycling at four power levels. We found that during incremental cycling exercise the pedalling effectiveness, smoothness and cyclist's swaying in all three planes increased according to the combined effect of the workload and fatigue. Cyclists with high FMS^{TM} score showed a lower bilateral pedalling asymmetry and a greater cycling specific postural stability, but showed no differences in the pedalling effectiveness and smoothness compared with the LS cyclists. Cyclist's FMS^{TM} score were moderately related with the stability components acting along the horizontal plane. The pedalling effectiveness, smoothness and bilateral asymmetry were inversely related to the components acting perpendicularly to the horizontal plane.

Key words: *Core stability, Pedalling effectiveness, Bilateral Asymmetry, Ground Reaction Force*

p-ISSN: 1691-7669/e-ISSN: 1691-9912/ISO 3297

DOI: 10.1515/ljss-2016-0009

Introduction

Road cycling is a time and energy consuming sport where the training and competitions last up to 7 hours (Jeukendrup, Craig & Hawley, 2000), vary largely in the intensity levels (Ebert, Martin, Stephens & Withers, 2006) and the effective use of strength and energy are important factors for the successful performance (Lucía, Hoyos, & Chicharro, 2001) and injury preventation (Holmes, Pruitt & Whalen, 1994). The metabolic cost (Broker & Gregor, 1994; Ettema & Lorås, 2009), muscle activity (Duc, Bertucci, Pernin, & Grappe, 2008) and biomechanical effectiveness (Gonzales & Hull, 1989; Coyle, et al., 1991) are indicators that quantity the economy of cycling. No direct relationships between those parameters have been found (Castronovo, Conforto, Schmid, Bibbo, & D'Alessio, 2013), but they are all sensitive to bicycle set up according to cyclists, and to pedalling cadence, workload, road incline, cyclist experience, riding position and fatigue (Fonda & Sarabon 2010). The biomechanical rationality in cycling is mainly measured as a torque delivery effectiveness from the legs to the pedals using specially designed pedals (Gonzales & Hull, 1989; Coyle, et al., 1991) or commercially available equipment (Bini & Hume 2014). But these methods account mainly the work of the lower limbs and less of the upper body motion. It is known that with the increase in workload not only the amount of the force delivery, direction and efficiency on the pedals are changing, but also the application of the force to the saddle and handlebars (Stone & Hull, 1995). In other words, when the reaction forces on the pedals increase, then the body weight is less supported by the saddle. Furthermore, accelerations of the trunk center of mass, hips and shoulders will increase (Costes, Turpin, Villeger, Moretto & Watier, 2015). In line with this it has been found that stabilisation of the upper body (McDaniel, Subudhi, & Martin, 2005) and balancing of the bicycle (Miller, Heath, Bressel & Smith, 2013) bear additional metabolic cost.

Stability of the cycling is also associated with the overuse injuries. Neck and back injuries are described as the most common overuse injuries associated with the long distance road cycling (Weiss, 1985; Wilber, Holland, Madison, & Loy, 1995; Dannenberg, Needle, Mullady & Kolodner, 1996). Increased lumbar flexion and rotation with an associated loss of stabilization of the lumbar spine have been show to be related to the lower back pain (Burnett, Cornelius, Dankaerts, et al., 2004). It has been also shown that after strenuous cycling exercises during a test of closed-eyed standing there is a significant increase in the instability of the antero-posterior, but not in the medio-lateral direction (Wiest, Diefenthaeler, Mota

& Carpes, 2011), that indicates to the fatigue in the postural stabilisation muscles after an intensive cycling.

Overuse problems in cycling can be attributed to a high number of pedalling repetitions produced by more or less asymmetric human body that is fixed as closed kinetic chain on the symmetrically designed bicycle (Holmes, Pruitt & Whalen, 1994). Existence of the asymmetry in the cycling kinematics (Edeline, et al., 2004), kinetics (Daly & Cavanagh 1976; Sanderson, 1990; Smak, Neptune & Hull, 1999; Carpes, et al., 2008) and muscle activation (Carpes, et al., 2011; Rannama & Port 2015) is well known. It seems that an increased effort improves the symmetry of pedalling kinetics and is also influenced by the pedalling rate (Carpes, Mota & Faria, 2010). At the same time the relationships between the pedalling symmetry and the cycling performance or the injury risk are not frequently discussed. The asymmetry in the strength of the bilateral knee extensors and the difference in the trunk motion kinematical between the left and right side during the pushing phases have been found to be negatively related with a short term sprint cycling performance (Rannama, Port, Bazanov, & Pedak, 2015), but there is also an opposite evidence that cyclists with a higher effectiveness in the bilaterally asymmetrical force delivery had better results in a 4 km time trial (Bini & Hume 2015). It has been proposed that the inclusion of the core stability training could have a beneficial effect in the terms of overuse injuries, and may also help to reduce the asymmetry of the movements, improve bike handling and stability (Fordham, Garbutt & Lopes, 2004; Asplund & Ross 2010). But there is a lack of empirical evidence of the relationships between the state of the core muscles and the variables of cycling performance and the injury incidence rate. Abt et al (2007) found that after fatiguing muscles of the torso the pedalling kinetics remained unchanged, but there was an alteration in the movement kinematics. Authors suggested that the training of the core strength for the greater torso stability within the saddle helps to maintain the alignment of the lower extremity for the greater force transmission to the pedals (Abt, et al., 2007).

In a last decade the Functional Movement Screen (FMS^{TM}) has become popular as a measurement method for the core stability and for the fundamental movement abilities in the monitoring of the training and in the scientific research (Kraus, Schütz, Taylor & Doyscher, 2014). The FMS^{TM} test includes 7 fundamental movement exercises that are evaluated in the terms of the quality of movement patterns, bilateral asymmetry and existence of the compensatory movements in a scale from 0 to 3 with a maximal overall score of 21 points (Cook, Burton, Hoogenboom & Voight

2014a and 2014b). This test complex is shown to have a good intra- and interrater reliability (Minick, et al., 2010; Teyhen, et al., 2012) and validity as a predictor of injury risk (Kiesel, Plisky, & Voight, 2007; Hotta, et al., 2015). Research is showing that the FMS^{TM} score equal to or lower than 14 is associated with a bigger injury risk in the professional football players (Kiesel, Plisky, & Voight, 2007) and among the competitive male runners (Hotta, et al., 2015). Validity of the FMS to predict sport performance is not as clear as demonstrated with the risk of injuries (Kraus, Schütz, Taylor, & Doyscher, 2014). Some suggest that the core stability and FMS^{TM} are not strong predictors of exercise performance (Okada, Huxel & Nesser, 2011), but there is evidence that high FMS^{TM} scored track and field athletes have better results in a longer time perspective, as less injuries disturb the training process (Chapman, Laymon & Arnold, 2014). Authors of the present study have not found empirical evidence relating the FMS^{TM} test results to the competitive road cyclist's pedalling technique and cycling specific postural stability. We believe that current study is the first attempt to analyse the cycling specific stability by measuring the changes in the ground reaction force components during the various work intensity levels in the cycling.

Purpose of the present study was to examine the changes in pedalling kinetics and ground reaction forces as a measure of the cycling stability during incremental cycling exercise, to compare the effectiveness of the pedalling technique and postural stability between high and low FMS^{TM} score cyclists and to analyse the relationships between cycling specific postural stability, pedalling kinetics and cyclists FMS^{TM} test scores.

Material and methods

Participants

Participants of current study were 31 competitive junior (n=9) and U23 (n=22) class male road cyclists (18.5±2.1 years, 181.1±6.0cm, 73.7±7.5 kg, Vo2max – 64.6±4.6ml/min/kg). All athletes had had at least 4 years of focused endurance cycling training and competition experience and had annual cycling distance above 12000km during the last season. 30 cyclists were right and 1 left leg dominant, assessed as ball kicking preference.

Study was performed after the end of a competitive season and before the start of a new preparation period. All participants were free of injuries and were informed of the research procedures and risks before the testing. All participants were told to avoid heavy or intensive trainings at least two days before the experiment.

Procedures

All experimental procedures for one person were made at same day. After arrival the cyclists performed following steps in the named order:

answered the questionnaire about training and health history of the past season; passed basic anthropometric measurement; performed Functional Movement Screen (FMS^{TM}) tests and completed incremental cycling exercise.

The FMS^{TM} consisted of the following sub-tests (Fig. 1): deep squat, hurdle step, in-line lunge, shoulder mobility test, active straight leg raise, trunk stability push-up and a rotary stability test, that assessing hip flexion, external and internal rotation strength and mobility, core stability and the mobility of shoulder joints (Cook, Burton, Hoogenboom & Voight, 2014a and 2014b) . All the sub-tests were performed at least three times and were registered from the different views, while the best trials were scored. All performed tests were captured by HD video camera (frame rate 60Hz).

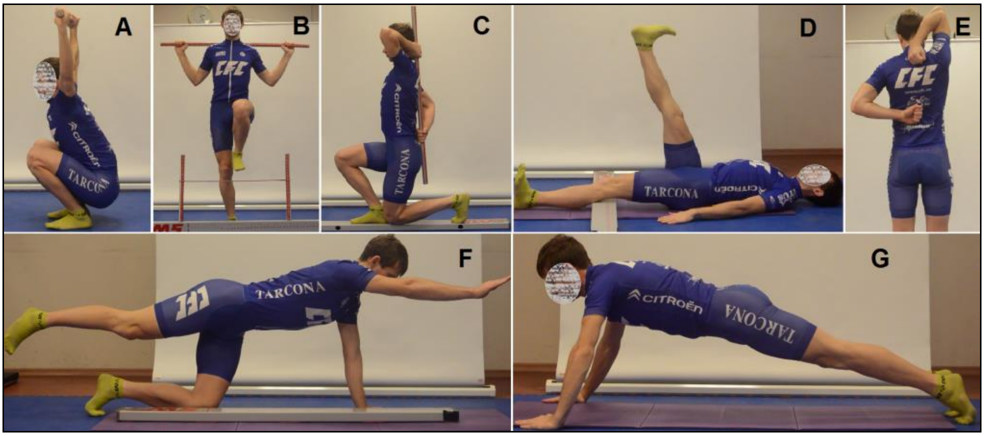


Figure 1. The *FMS^{TM}* tests (A – deep squat, B – hurdle step, C – in-line lunge, D – active straight leg raise, E – shoulder mobility test, F – trunk stability push-up, G – rotary stability test)

Experimental cycling exercise was performed using the personal racing bikes, which were mounted on the cycling ergometer Cyclus 2 (Avantronic, Cyclus 2, and Leipzig, Germany) that allows lateral inclination of the bike to matches the real life cycling. Exercise protocol consisted of a 10 minutes warm-up of steady ride at the power level of 100W and was followed by the incremental cycling exercise: target cadence 90±5 revolution/min (rpm), initial workload of 100W and the workload increased by 25W after every 2 minute until exhaustion. Exhaustion was defined as the point when the participant was no longer capable of maintaining a cadence of 70rpm. The cycling tests were conducted in sitting position hands on the drops (Fig. 2A).

During and after 3 minute of the cycling exercise the heart rate and breath by breath pulmonary O_2 (VO_2), CO_2 production ($\dot{V}CO_2$), and expired minute ventilation ($\dot{V}E$) were measured continuously with the Cosmed Quark CPET metabolic analyser (Rome, Italy). Prior to each test, system was calibrated according to the manufacturer's instructions.

To measure the *pedalling kinetic*s each participants bicycle was equipped with a pair of Garmin Vector power meter pedals (Garmin Vector™). Same Vector pedals were used throughout and were calibrated before the each testing session according to manufacturer's guidelines.

Cycling specific postural stability was measured with two six component Kistler 9286B force plates (virtually combined surface of 0.6x1.4m plate) connected rigidly with Cyclus2 ergometer supports (Fig. 2) – one plate was under the bicycle front fork support (fixed with double side tape) and the other plate was under the ergometer load unit, connected with bicycle rear fork (fixed with special plate). The ergometer weight was set to zero before the cyclist sat on the bicycle, therefore only riders mass was counted. During the incremental test 6 GRF components were captured with frequency of 200Hz: 3 linear components along medio-lateral (Fx), anterior-posterior (Fy) and vertical axis (Fz) relative to bicycle direction and 3 rotational moments (Mx, My, Mz) around those axis (Fig. 2A).

All data from Cyclus2 ergometer, Cosmed Quark CPET metabolic cart, Garmin Vector pedals and Kistler Force plates were synchronized in time and captured continuously. Data from the test was analysed after the test.

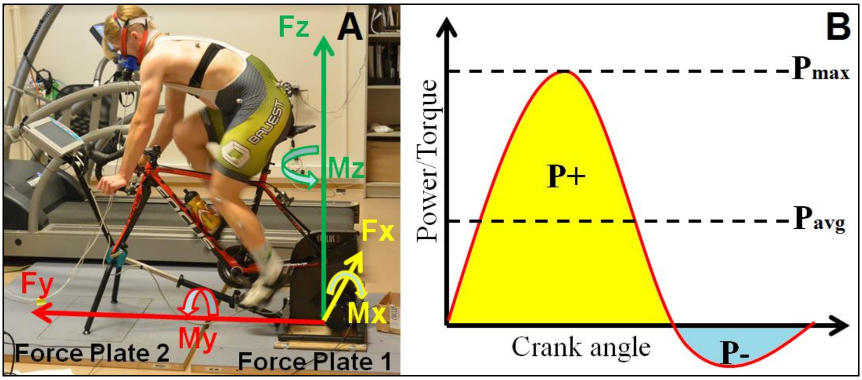


Figure 2. The placement of force plates and GRF components (Figure A); computational parameters for Torque Effectiveness (TE) and Pedalling Smoothness (PS) (Figure B)

Measures

Captured video of FMS^{TM} tests were analysed with the video analysis software Kinovea 0.8.24 by an experienced (22 years of practice) physical therapist with 6 years of experience with the FMS. The movement quality of all 7 FMS^{TM} were evaluated in four point ranking system: „3“ – the correct performance of the movement pattern, „2“ – the subject needs compensatory movements to solve the sub-test, „1“ – the individual is not able to perform the movement pattern at all, „0“ – subjects feel pain while performing a exercise. Five of the seven FMS^{TM} items (hurdle step, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability test) are performed independently on the right and left sides of the body and the lowest score of the two sides were accounted. All of the seven sub-test scores were summed to a total FMS^{TM} score, resulting in a maximum of possible 21 points. (Cook, Burton, Hoogenboom & Voight, 2014a and 2014b)

According to a previous study cyclists were divided into low FMS score (LS – 4 or less point) and high FMS score (HS – over the 14 points) group (Kiesel, Plisky & Voight, 2007; Hotta, et al., 2015).

The maximal aerobic power (VO_2max) and ventilatory threshold levels assessment were performed using Cosmed PFT Ergo software independently by two experienced researchers. The first (aerobic level – AeL) and second ventilatory thresholds level (Anaerobic level – AnL) were estimated by methods described and validated by Weston and Gabbett (2001). The indicators for AeL were: the first nonlinear increases in the VE curve; the first increase VE/VO_2 curve while the VE/VCO_2 slope remains constant; the inflexion point between VO_2 and VCO_2. The AnL was determined by the second nonlinear increase in VE and the second nonlinear increase in VE/VO_2 slope with simultaneous increase in VE/VCO_2. The maximal aerobic oxygen uptake (VO_2max) was determined as the highest 30sec average during the exercise. For the future analyses the AeL, AnL and VO_2max power levels were determined as increments where the level moment was achieved. When the certain intensity level was achieved during first 30sec of the incremental step the previous increment was chosen.

The kinetics of the pedalling were described by the pedalling power (POW), pedalling Torque Effectiveness (TE=(P+)/[(P+)+|P-|]*100(%)) and pedalling smoothness (PS=Pavg/Pmax*100(%)) collected from Garmin Vector pedals with 1sec interval, independently for the left and right sides throughout the experimental exercise(Fig. 2B). Also the absolute symmetry index (ASI (%)=100*|DO-ND|/0.5*(DO+ND)) was calculated (Robinson, Herzog & Nigg, 1987) for POW, TE and PS. Average values of the period of 30 seconds during the middle of the second minute of a 150W workload, as well as for AeL, AnL and for the VO_2max levels were used for the analysis. The TE and PS values were expressed as a mean of dominant and nondominant leg.

The drift of force plates were corrected by reference values and the force and moment values from force plates were filtered with 20Hz zero lag 4th order Butterworth low pass filter to remove high frequency noise. The standard deviation (SD) of each GRF component over the 30sec period in 150W, AeL, AnL VO_2max levels were computed to measure the direction specific linear and angular force dispersion from average (or zero) value according to all 3 plane of space (Duarte & Freitas 2010). The SD values were normalised with cyclists body weight (Fx/BW, Fy/BW, Fz/BW, Mx/BW, My/BW, Mz/BW) in percent's (%).

Analysis

Data analyses were performed by using the IBM SPSS Statistics version 21.0 for Windows. Descriptive statistics were computed for all variables and for every test phase and expressed as a mean±SD. All the data were tested for their normal distribution (Kolmogorov-Smirnov test). The significance of differences in anthropometric variables between HS and LS group were controlled by student t test for independent data. A multivariate ANOVA was applied to assess differences between intensity levels and between LS and HS groups in pedalling kinetics, GRF components and VO_2 values. Pearson (for normally distributed parameters) and Spearman (for not normally distributed and FMS^{TM} test and sub tests data) tests were used for correlation analysis between FMS test values, pedaling kinetics, ASI(%) and body mass corrected GRF components were measured at the AeL and AnL. Significance level was set at $p<0.05$.

Results

FMS^{TM} test results

The descriptive statistics of FMS^{TM} tests and it sub-tests score are presented in table 1. The lower scores for cyclists associated with Rotary Stability test, where only one person was able to perform exercise correctly and 13 persons performed the simplified version of the exercise with compensatory movements. The highest average score had Deep Squad test, because there was no cyclists who scored “1” or “0”, but most athletes (n=22) performed this exercise also with compensatory movements, as well as in the other 6 tests. Most cyclists (n=19) had total FMS^{TM} test score equal or lower than 14 points (LS group), 12 persons had score over to this critical line (HS group).

Table 1

The descriptive statistics of FMS^{TM} test and it sub-tests score values

n=31	FMS score	Deep Squat	Hurdle Step	In-line Lunge	Active SLR	Shoulder Mobility	Rotary Stability	Pushup
Minimum	12 (n=6)	2 (n=22)	2 (n=28)	1 (n=3)	1 (n=3)	1 (n=5)	1 (n=13)	1 (n=1)
Maximum	20 (n=1)	3 (n=9)	3 (n=3)	3 (n=6)	3 (n=7)	3 (n=7)	3 (n=1)	3 (n=4)
Mode	13 (n=7)	2	2	2 (n=22)	2 (n=21)	2 (n=19)	2 (n=17)	2 (n=26)
Mean	14.13	2.29	2.10	2.10	2.13	2.06	1.61	1.97
SD	1.80	0.46	0.30	0.54	0.56	0.63	0.56	0.55

The comparison of incremental cycling exercise results in high and low FMS scored cyclist groups

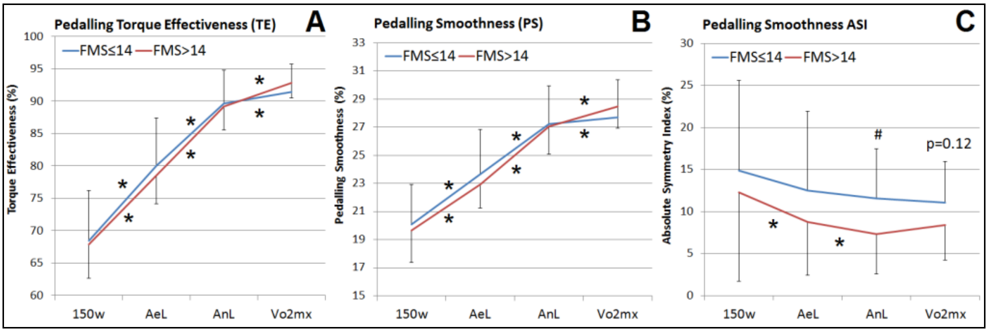
The LS and HS groups did not differed between anthropometric parameters (age 18.6 2.0± and 18.3±2.3y, height 181.7±6.5 and 180.1±5.3cm, body mass 73.5±8.6 and 74.3±5.5kg respectively). Also there was no significant differences in cadence, power and VO_2 values in any intensity level (Table 2).

Table 2

The descriptive statistics of intensity level cadence, power and body mass corrected VO_2 values in low and high FMS scored cyclist groups

			AeL			AnL			VO_2max		
	Group	n	Mean	SD	p	Mean	SD	p	Mean	SD	p
Cad (RPM)	FMS≤14	19	90.2	3.9	.81	91.6	4.8	.49	91.2	6.0	.18
	FMS>14	12	90.5	3.0		90.5	2.9		89.4	2.7	
Power (W)	FMS≤14	19	211.6	29.1	.95	303.4	37.9	.76	340.0	37.7	.97
	FMS>14	12	211.0	22.7		299.6	25.2		339.5	26.7	
Power/BW (W/kg)	FMS≤14	19	2.9	0.3	.71	4.1	0.3	.39	4.7	0.4	.61
	FMS>14	12	2.8	0.3		4.0	0.3		4.6	0.4	
VO_2 (ml/kg/min)	FMS≤14	19	45.4	4.0	.79	59.1	4.4	.24	65.2	4.5	.33
	FMS>14	12	45.0	4.3		57.2	4.2		63.6	4.7	

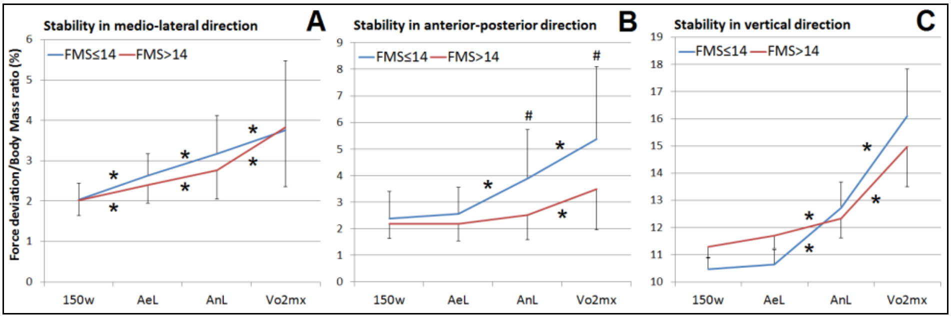
In figure 3 are presented dynamics of pedalling TE, PS and PS asymmetry in LS and HS group. During the incremental exercise in both groups the TE and PS values significantly increased, but there was no significance between FMS^{TM} scores groups' differences in pedalling efficiency values (Fig. 3A and B). At the same time the bilateral asymmetry in PS was notably higher in LS group in AnL and same tendency (p=0.12) existed in VO_2max level (Fig. 3C). No differences between groups were found in POW and TE ASI in any workload.



(*- significant difference between intensity levels; #- significant difference between groups $p<0.05$)

Figure 3. Dynamics of average (+/-SD) Torque Effectiveness (TE) (Fig. 3A) and Pedalling Smoothness (PS) (Fig. 3B) and bilateral PS symmetry values (Fig. 3C) during incremental cycling exercise in low (FMS≤14; n=19) and high (FMS>14; n=12) FMS^{TM} score cyclist's group

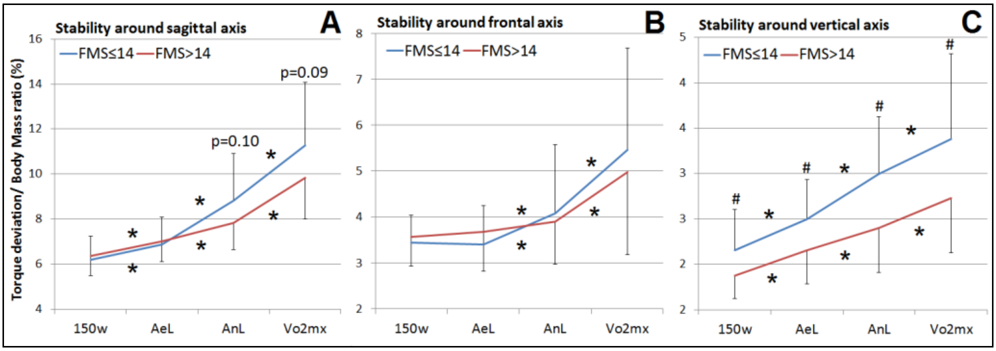
The comparison of linear GRF components deviations (Fig. 4) referred to a significantly ($p<0.05$) higher anterior-posterior direction force (Fy/BW) deviations in LS group at higher intensity levels (Fig. 4A) no differences were found in the force deviations in the other two direction. During the incremental test the medio-lateral (Fx/BW) deviation increased with every intensity level, but in anterior-posterior (Fy/BW) and vertical direction (Fz/BW) the force deviation increased significantly after AeL (Figure 4 B and C).



(*- significant difference between intensity levels; #- significant difference between groups $p<0.05$)

Figure 4. Dynamics of average (+/-SD) body mass normalised GRF linear components deviation along medio-lateral/Fx (Fig. 4A), anterior-posterior/Fy (Fig. 4B) and vertical/Fz direction (Fig. 4C) during incremental cycling exercise in low and high FMS^{TM} score cyclist's group

The rotational GRF components increased significantly along the workload increase, except My/BW, where there was no differences between the values at two lower intensity level in both FMS^{TM} score group. The cyclists from LS group had a significantly higher rotational torque deviation around vertical axis in all of the intensity levels (Fig. 5C). Same tendency existed in the higher intensity levels deviation of the momentum around the sagittal (Mx/BW) axis (Fig. 5A). No differences between the groups were found in the deviations around the frontal axis moment (Fig. 5B).



(*- significant difference between intensity levels; #- significant difference between groups p<0.05)

Figure 5. Dynamics of average (+/-SD) body mass normalised GRF rotational components deviation around sagittal/Mx (Figure 4A), frontal/My (Figure 4B) and vertical/Fz (Figure 4C) axis during incremental cycling exercise in low and high FMS^{TM} score cyclist's group

Relationship between FMS^{TM} test score, pedalling kinetics and GRF components deviation

The correlation analysis results are given in Tables 3, 4 and 5. There were no significant correlations between the FMS^{TM} test composite score and the pedalling kinetic variables or the bilateral pedalling asymmetry values (Table 3).

Table 3

The Correlations between FMS^{TM} score and pedalling kinetics variables

n=31	AeL					AnL				
	FMS score	TE	PS	Pow ASI	TE ASI	FMS score	TE	PS	Pow ASI	TE ASI
TE	-.30	1				-.27	1			
PS	-.23	*.90***	1			-.14	*.83***	1		
Pow ASI	.19	-.11	.02	1		.07	-.24	-.20	1	
TE ASI	.15	*-.54***	*-.39**	*.62***	1	.02	*-.55***	*-.44**	*.63***	1
PS ASI	-.04	*-.50***	*-.39**	.26	*.75***	-.16	*-.42**	-.27	.17	*.49***

* Correlation is significant at the p<0.05 level (2-tailed); ** Correlation is significant at the p<0.01 level (2-tailed)

Significant moderately strong negative correlations were found between the composite FMS score and body mass corrected GRF deviation components – higher FMS^{TM} score was related with lower deviation values of Mz/BW in AeL and AnL and Fy/BW in AnL. The higher value in Deep Squad sub-test associated with smaller deviations of GRF component associated with the sagittal direction lineary (Fx/BW) and around the vertical axis rotational (Mz/BW) motions. Also in-line Lung test correlated negatively with the Fy/BW deviation in AnL and Rotary Stability test score with Mz/BW in AeL. All GRF components, which were correlated with FMS test results, were related with the force actions in the horizontal plane and no correlation were found with GRF components acting perpendicular to horizontal plane (Table 4).

Table 4

The Correlations between FMS tests scores and body weight corrected GRF components deviation values

	AeL						AnL					
n=31	Fx/ BW	Fy/ BW	Fz/ BW	Mx/ BW	My/ BW	Mz/ BW	Fx/ BW	Fy/ BW	Fz/ BW	Mx/ BW	My/ BW	Mz/ BW
FMS score	-.22	-.26	.27	.03	.12		-.09	*-.39**	.03	-.21	.01	*-.46**
Deep Squat	*-.40**	-.26	.07	-.01	.00	*-.45**	*-.49***	-.30	.02	-.14	-.06	*-.41**
Hurdle Step	.18	-.07	.32	.26	.18	-.02	.26	-.27	.13	.15	.10	.12
In-line Lunge	-.08	-.30	.14	-.09	.01	-.25	.03	*-.36**	.01	-.15	-.04	-.29
Active SLR	.02	.05	.09	-.07	.10	.07	.28	.10	-.17	-.19	-.08	.21
Shoulder Mobility	-.20	-.30	-.09	-.32	-.12	-.18	-.02	-.09	-.19	-.31	-.13	-.25
Rotary Stability	-.15	-.13	.32	.21	.23	*-.40**	-.13	-.28	.23	.00	.18	-.32
Pushup	.13	-.09	-.02	.04	-.15	-.01	-.07	-.17	.01	.05	-.09	-.27

* Correlation is significant at the $p<0.05$ level (2-tailed); ** Correlation is significant at the $p<0.01$ level (2-tailed)

The TE, PE and asymmetry was mostly related with GRF components associated with the movements perpendicular to the horizontal plane (Fz, My and Mx) and had almost no significant correlations with the GRF components acting in the horizontal plane (Fx, Fy and Mz). The higher TE and PS associated moderately with the lower rotational moment deviation around the sagittal axis during AeL and AnL cycling. Also the ASI of TE and PS associated with named GRF component deviation, but in the opposite direction.

Table 5

The Correlations between pedalling kinetics, bilateral asymmetry and body weight corrected GRF components deviation values

n=31	AeL						AnL					
	Fx/ BW	Fy/ BW	Fz/ BW	Mx/ BW	My/ BW	Mz/ BW	Fx/ BW	Fy/ BW	Fz/ BW	Mx/ BW	My/ BW	Mz/ BW
TE	.00	-.32	-.48**	-.61**	-.40*	-.31	-.04	-.15	-.43*	-.46**	-.33	-.24
PS	-.08	-.28	-.35	-.56**	-.26	-.34	.07	-.08	-.26	-.37*	-.16	-.24
Pow ASI	-.03	.08	.37*	.27	.29	-.03	.01	-.09	.11	.06	.06	.02
TE ASI	-.03	.22	.47**	.59**	.44*	.32	-.01	.15	.19	.24	.17	.21
PS ASI	-.19	.26	.24	.43*	.26	.31	.02	.38*	.14	.29	.16	.28

* Correlation is significant at the p<0.05 level (2-tailed); ** Correlation is significant at the p<0.01 level (2-tailed)

Discussion

The aim of the present study was to evaluate the young road cyclist's core stability and ability to perform fundamental movements. The results of FMS^{TM} test showed that more than a half of (n=19) cyclists achieved the score 14 points or less and were in raising injury risk group after the competition period (Kiesel, Plisky, & Voight, 2007; Hotta, et al., 2015). At the same time the mean FMS^{TM} score for the road cyclist's in the current study was 14.1±1.8, which is similar to results of same aged competitive male runners (14.1±2.3) (Hotta, et al., 2015). The less scored sub-test's for cyclists were Rotary Stability (1.61±0.56) and Pushup (1.97±0.55), this points to the problems with trunk and hip region muscles stability (Cook, Burton, Hoogenboom & Voight, 2014a and 2014b). The poor results in Rotational stability test were related with higher horizontal plane rotational movements in cycling. Similar to our findings the poorest sub-test results for male runner's population were also in the Rotary Stability test (1.5±0.51 to 1.6±0.6) (Agresta, Slobodinsky & Tucker, 2014; Hotta et al, 2015). But different from runners (Agresta, Slobodinsky & Tucker, 2014; Hotta, et al., 2015) (scores between 1.3±0.7 to 2.0±0.47) the cyclists had relatively higher Deep Squad scores (2.29± 0.46). At the same time the Deep Squad performance with compensatory movements associated with lower cycling specific postural stability in medio-lateral direction and around vertical axis, for the runners this sub-test results were the most sensitive for injury prediction (Hotta, et al., 2015).

During the incremental cycling the postural stability decreased and this is in line with findings of Costes et al. (2015) what along with power increase the acceleration forces directed to pelvis and upper body raise. In the dynamics of horizontal plane GRF components deviation were found significant differences between LS and HS cyclists groups. The LS group had larger body swaying around vertical axis in all workloads and anterior-posterior direction on higher workloads in anterior-posterior direction, which seems to be sensitive direction for stability decrease during strenuous cycling exercise (Wiest, Diefenthaeler, Mota & Carpes, 2011). The named results are supporting the previous statements about beneficial effect of the core stability training on cycling stability (Fordham, Garbutt & Lopes, 2004; Asplund & Ross, 2010). At the same time the FMS^{TM} score did not have any significant relationships with pedalling kinetic variables like TE and PS. The previous research of Abt et al. (2007) also found that trunk muscles state does not alter the pedalling kinetics.

The smoother, less negative torque producing pedalling technique and lower bilateral asymmetry were related with smaller vertical direction linear movement and lower cyclist’s body swaying around sagittal and frontal axis of bicycle. These correlations were stronger at AeL cycling and were less significant in AnL. One of the reasons may be the raised efficiency level and lowered asymmetry that was found in our study and was in line also with previous findings (Sanderson, et al., 1991; Carpes, et al., 2008).

Conclusions

Results of the present study indicate that during an incremental cycling exercise the pedalling effectiveness, smoothness and cyclist’s body swaying in all three planes are increasing according to the combined effect of workload and fatigue. The cyclists with FMS^{TM} score higher than 14 showed lower bilateral pedalling asymmetry and greater cycling specific postural stability, but had no differences in the pedalling effectiveness and smoothness compared with the cyclists of a low FMS^{TM} score. Cyclists FMS^{TM} score was moderately linked with the stability components acting along the horizontal plane. The pedalling effectiveness, smoothness and bilateral asymmetry were inversely related with the components acting perpendicularly to the horizontal plane.

References

1. Abt, J. P., Smoliga, J. M., Brick, M. J., Jolly, J. T., Lephart, S. M., & Fu, F. H. (2007). Relationship between cycling mechanics and core stability. *The Journal of Strength & Conditioning Research*, *21*(4), 1300-1304. http://dx.doi.org/10.1519/00124278-200711000-00056

2. Agresta, C., Slobodinsky, M., & Tucker, C. (2014). Functional movement ScreenTM--normative values in healthy distance runners. *Int J Sports Med*,*35*(14), 1203-7. http://dx.doi.org/10.1055/s-0034-1382055
3. Asplund, C., & Ross, M. (2010). Core stability and bicycling. *Current sports medicine reports*, *9*(3), 155-160. http://dx.doi.org/10.1249/jsr.0b013e3181de0f91
4. Bini, R. R., & Hume, P. A. (2014). Assessment of Bilateral Asymmetry in Cycling Using a Commercial Instrumented Crank System and Instrumented Pedals. *International Journal of Sports Physiology and Performance*, 9(5), 876-881 http://dx.doi.Org/10.1123/ijspp.2013-0494
5. Broker, J. P. & Gregor, R. J. (1994). Mechanical energy management in cycling: source relations and energy expenditure. *Medicine and Science in Sports and Exercise*, 26(1), 64–74. http://dx.doi.org/10.1249/00005768-199401000-00012
6. Carpes, F. P., Rossato, M., Faria, I. E., & Mota, C. B. (2007). Bilateral pedaling asymmetry during a simulated 40-km cycling time-trial. *Journal of Sports Medicine and Physical Fitness*, 47, 51–57. http://dx.doi.org/10.1249/00005768-200605001-01667
7. Carpes, F. P., Rossato, M., Faria, I. E., & Mota, C. B. (2008). During incremental exercise cyclists improve bilateral pedalling symmetry. *Brazilian Journal of Biomotricity*, 2(3), 155-159. http://brjb.com.br/
8. Carpes, F. P., Diefenthaeler, F., Bini, R. R., Stefanyshyn, D. J., Faria, I. E. & Mota, C. B. (2011). Influence of leg preference on bilateral muscle activation during cycling. *Journal of Sports Sciences*, 29(2), 151-159.
http://dx.doi.org/10.1080/02640414.2010.526625
9. Castronovo, A. M., Conforto, S., Schmid, M., Bibbo, D., & D'Alessio, T. (2013). How to assess performance in cycling: the multivariate nature of influencing factors and related indicators. *Frontiers in physiology*, *4*. http://dx.doi.org/10.3389/fphys.2013.00116
10. Chapman, R. F., Laymon, A. S., & Arnold, T. (2014). Functional movement scores and longitudinal performance outcomes in elite track and field athletes. *International Journal of Sports Physiology & Performance*, *9*(2), 203-2012. http://dx.doi.org/10.1123/ijspp.2012-0329
11. Cook, G., Burton, L., Hoogenboom, B. J., & Voight, M. (2014a). Functional movement screening: the use of fundamental movements as an assessment of function-part 1. *International journal of sports physical therapy*, *9*(3), 396-409.
12. Cook, G., Burton, L., Hoogenboom, B. J., & Voight, M. (2014b). Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *International journal of sports physical therapy*, *9*(4), 549-563.
13. Costes, A., Turpin, N. A., Villeger, D., Moretto, P., & Watier, B. (2015). A reduction of the saddle vertical force triggers the sit–stand transition in

cycling. *Journal of biomechanics*, *48*(12), 2998-3003. http://dx.doi.org/10.1016/j.jbiomech.2015.07.035

14. Daly, D. J., & Cavanagh, P. R. (1976). Asymmetry in bicycle ergometer pedalling. *Medicine and Science in Sports and Exercise*, 8, 204–208. http://dx.doi.org/10.1249/00005768-197600830-00013
15. Dannenberg, A. L., Needle, S., Mullady, D., & Kolodner, K. B. (1996). Predictors of injury among 1638 riders in a recreational long-distance bicycle tour: Cycle Across Maryland. *The American journal of sports medicine*,*24*(6), 747-753. http://dx.doi.org/10.1177/036354659602400608
16. Duarte, M., & Freitas, S. M. (2010). Revision of posturography based on force plate for balance evaluation. *Brazilian Journal of physical therapy*,*14*(3), 183-192.
17. Duc, S., Bertucci, W., Pernin, J. N., & Grappe, F. (2008). Muscular activity during uphill cycling: effect of slope, posture, hand grip position and constrained bicycle lateral sways. *Journal of Electromyography and Kinesiology*, *18*(1), 116-127. http://dx.doi.org/10.1016/j.jelekin.2006.09.007
18. Ebert, T.R., Martin, D.T., Stephens, B. & Withers, R.T. (2006). Power Output during a Professional Men's Road-Cycling Tour. *International Journal of Sports Physiology and Performance*, 1(4), 324-335
19. Edeline, O., Polin, D., Tourny-Chollet, C., & Weber, J. (2004). Effect of workload on bilateral pedaling kinematics in nontrained cyclists. *Journal of Human Movement Studies*, 46, 493–517.
20. Ettema, G., & Lorås, H. W. (2009). Efficiency in cycling: a review. *European journal of applied physiology*, *106*(1), 1-14. http://dx.doi.org/10.1007/s00421-009-1008-7
21. Fonda, B., & Sarabon, N. (2010). Biomechanics of cycling. *Sport Science Review*, *19*(1-2), 187-210. http://dx.doi.org/10.2478/v10237-011-0012-0
22. Fordham, S., Garbutt, G., & Lopes, P. (2004). Epidemiology of injuries in adventure racing athletes. *British journal of sports medicine*, 38(3), 300-303. http://dx.doi.org/10.1136/bjsm.2002.003350
23. Holmes, J. C., Pruitt, A. L., & Whalen, N. J. (1994). Lower extremity overuse in bicycling. *Clinics in sports medicine*, *13*(1), 187-205.
http://dx.doi.org/10.1111/j.0954-6820.1986.tb08947.x
24. Hotta, T., Nishiguchi, S., Fukutani, N., Tashiro, Y., Adachi, D., Morino, S., ... & Aoyama, T. (2015). Functional Movement Screen for Predicting Running Injuries in 18-to 24-Year-Old Competitive Male Runners. *The Journal of Strength & Conditioning Research*, *29*(10), 2808-2815. http://dx.doi.org/10.1519/jsc.0000000000000962
25. 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. http://dx.doi.org/10.1016/s1440-2440(00)80008-0
26. Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen. *N Am J Sports Phys Ther*, *2*(3), 147-158.

27. Kraus, K., Schütz, E., Taylor, W. R., & Doyscher, R. (2014). Efficacy of the functional movement screen: a review. *The Journal of Strength & Conditioning Research*, *28*(12), 3571-3584. http://dx.doi.org/10.1519/jsc.0000000000000556
28. Lucía, A., Hoyos, J., & Chicharro, J. L. (2001). Physiology of professional road cycling. *Sports Medicine*, *31*(5), 325-337. http://dx.doi.org/10.2165/00007256-200131050-00004
29. Martin, J. C., & Brown, N. T. (2009). Joint-specific power production and fatigue during maximal cycling. *Journal Of Biomechanics*, *42*(4), 474-479. http://dx.doi.org/10.1016/j.jbiomech.2008.11.015
30. McDaniel, J., Subudhi, A., & Martin, J. C. (2005). Torso stabilization reduces the metabolic cost of producing cycling power. *Canadian journal of applied physiology*, *30*(4), 433-441. http://dx.doi.org/10.1139/h05-132
31. Miller, A. I., Heath, E. M., Bressel, E., & Smith, G. A. (2013). The metabolic cost of balance in Cycling. *Journal of Science and Cycling*, *2*(2), 20.
32. Minick, K. I., Kiesel, K. B., Burton, L., Taylor, A., Plisky, P., & Butler, R. J. (2010). Interrater reliability of the functional movement screen. *The Journal of Strength & Conditioning Research*, *24*(2), 479-486. http://dx.doi.org/10.1519/jsc.0b013e3181c09c04
33. Okada, T., Huxel, K. C., & Nesser, T. W. (2011). Relationship between core stability, functional movement, and performance. *The Journal of Strength & Conditioning Research*, 25(1), 252-261. http://dx.doi.org/10.1519/jsc.0b013e3181b22b3e
34. Rannama, I., & Port, K. (2015) Bilateral biomechanical asymmetry during 30 seconds isokinetic sprint-cycling exercise. Lase Journal of Sport Science, 6(2), 3-16. DOI: 10.1515/ljss-2016-0001
35. Rannama, I., Port, K., Bazanov, B., & Pedak, K. (2015). Sprint cycling performance and asymmetry. *Journal of Human Sport and Exercise*. 10(Proc1): S247-S258. http://dx.doi.org/10.14198/jhse.2015.10.proc1.12
36. Robinson, R.O., Herzog, W. & Nigg, B.M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *Journal of Manipulative Physiological Theraphy*, 10(4), 172—176.
37. Sanderson, D. J. (1990). The influence of cadence and power output on asymmetry of force application during steady-rate cycling. *Journal of Human Movement Studies*, 19, 1–9.
38. Smak, W., Neptune, R. R., & Hull M. L. (1999). The influence of pedaling rate on bilateral asymmetry in cycling. *Journal of Biomechanics*, 32(9), 899 — 906. http://dx.doi.org/10.1016/s0021-9290(99)00090-1
39. Stone, C., & Hull, M. L. (1995). The effect of rider weight on rider-induced loads during common cycling situations. *Journal of biomechanics*, *28*(4), 365-375.http://dx.doi.org/10.1016/0021-9290(94)00102-a

40. Teyhen, D. S., Shaffer, S. W., Lorenson, C. L., Halfpap, J. P., Donofry, D. F., Walker, M. J., ... & Childs, J. D. (2012). The functional movement screen: A reliability study. *journal of orthopaedic & sports physical therapy*, *42*(6), 530-540. http://dx.doi.org/10.2519/jospt.2012.3838
41. Wasserman, K., Whipp, B. J., Koyl, S. N., & Beaver, W. L. (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of applied physiology*, *35*(2), 236-243.
42. Weiss, B. D. (1985). Nontraumatic injuries in amateur long distance bicyclists. *The American journal of sports medicine*, *13*(3), 187-192. http://dx.doi.org/10.1177/036354658501300308
43. Weston, S. B., & Gabbett, T. J. (2001). Reproducibility of ventilation of thresholds in trained cyclists during ramp cycle exercise. *Journal of Science and Medicine in Sport*, *4*(3), 357-366. http://dx.doi.org/10.1016/s1440-2440(01)80044-x
44. Wiest, M. J., Diefenthaeler, F., Mota, C. B., & Carpes, F. P. (2011). Changes in postural stability following strenuous running and cycling. *Journal of Physical Education and Sport*, *11*(4), 406.
45. Wilber, C. A., Holland, G. J., Madison, R. E., & Loy, S. F. (1995). An epidemiological analysis of overuse injuries among recreational cyclists. *International journal of sports medicine*, *16*(3), 201-206. http://dx.doi.org/10.1055/s-2007-972992

Submitted: May 06, 2016
Accepted: June 20, 2016