Original Article

Cycling specific postural stability during incremental exercise: The relationship with cyclists functional movement screen score

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ABSTRACT

The purpose of this study was to characterise the changes in the power of the normalised ground reaction forces and COP swaying, as measures of the cycling stability and effectiveness of full body motion during an incremental cycling exercise; and to examine the relationships between cycling specific postural stability and cyclists ability to perform functional movements, measured by the FMS test.38 competitive road cyclists (19.2±2.3 yrs., 181.7±6.6 cm, 74.3±7.3 kg) performed Functional Movement Screen (FMS) test to evaluate their musculoskeletal state. Experimental cycling exercise was performed using the cyclist's personal racing bikes mounted on the cycling ergometer Cyclus 2, which were fixed on two Kistler 9286B force plate. The 6 ground reaction force (GRF) components (3 linear and 3 angular), COP movement deviation and sway velocity were measured during incremental cycling exercise (step 2 min, increment 25W). Postural stability measures were calculated as power corrected standard deviations of center of pressure (COP) and GRF components signals during 30 sec cycling in every incremental step. The paired t-test was used to control differences in postural stability measures between intensity levels and correlation analyses was used to evaluate relationships between postural stability and FMS scores. Results of the study indicate that most integrative cycling specific posture stability measure is COP sway velocity that is also most sensitive predictor of cyclist's musculoskeletal state, measured by the FMS test. During an incremental cycling exercise the power normalised postural swaying decreased up to the intensity at the level of anaerobic threshold and during the level of the maximal aerobic power the postural stability decreased significantly. **Key words:** FORCE PLATE, GRF, CYCLUS2, POSTURAL SWAY

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INTRODUCTION

Up to 100 starts during the annual season of road cycling competitions of long duration with variable levels of intensity set a high demands on a cyclist's ability to use effectively the strength and energy (Ebert et al., 2006; Jeukendrup et al., 2000; Lucía et al., 2001). The economy of cycling can be measured by physiological methods as the ratio of metabolic energy transformation to mechanical work (Broker & Gregor, 1994; Ettema & Lorås, 2009) or to integrated muscular activity of main (leg) muscle groups (Duc et al., 2008). The biomechanical effectiveness of cycling pedalling technique is traditionally measured as the ratio between tangential (perpendicular to bicycle crank arm) force to the resultant force applied to the pedals (Gonzales & Hull, 1989; Coyle et al., 1991). No direct relationships between the metabolic economy and the effectiveness of force transfer have been found (Castronovo et al., 2013). Probably this biological signal is masked by the large inter-individual variability in cyclist's physiological and neuromuscular states, as well as by the metabolic cost of the work done by the whole body while the pedalling forces are mainly dependent of the performance of lower limbs. At the same time metabolic state and mechanical force transfer from foot to pedal are intra-individually affected by bike set up (Peveler & Green, 2011; Bini et al., 2014a; Menard et al., 2016), riding position (Gnehm et al.,1997; Millet et al., 2002; Bini et al., 2014b), pedalling cadence (Neptune & Herzog, 1999; Patterson & Moreno, 1990), level of workload (Ettema & Lorås, 2009), training experience (Coyle, 2005) and fatigue (Passfield & Doust, 2000). However, it is long known that the professional level cyclists have better metabolic economy (Lucia et al., 1998) and the latest findings conclude that top level cyclists exhibit superior force delivery effectiveness during pedalling (García-López et al., 2016).

As mentioned previously the biomechanical rationality in cycling is mainly measured as torque delivery effectiveness from the legs to the cranks, but lately more attention is paid to upper body biomechanics and force generation patterns to saddle and handlebars (Costes et al., 2015; Menard, et al., 2016). It is found that increase in workload produces higher accelerations of the centre of the mass of the trunk (COM) (Costes et al., 2015) and the resulting need of stabilisation of the upper body (McDaniel et al., 2005) and balancing of the bicycle (Miller et al., 2013) are additional sources of the metabolic cost. At the same time the knowledge regarding cyclist's postural stability during pedalling is limited. Usually the postural stability is analysed by capturing the ground reaction forces (GRF) and computing the motion patterns of centre of pressure (COP). The usage of force plates in postural stability analysis of cycling on the ergometer is limited with the design of the ergometer (rigid linkage or limited lateral inclination) and attachment to force plates, that may cause overestimation of torque component around frontal axis and because of that the results collected with different equipment set-ups may not be comparable.

Upper body motion and cycling stability is also important factor of injury prevention, because common overuse injuries in long distance road cycling are associated with neck and back region (Weiss, 1985; Wilber et al., 1995; Dannenberg et al., 1996). There are indications that intensive cycling will cause fatigue in muscles for postural stabilisation (Wiest et al., 2011) and loss of stabilization in the lumbar spine with increased lumbar flexion is related with lower back pain (Burnett et al., 2004). 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 improve bike handling and postural stability (Fordham et al., 2004; Asplund & Ross, 2010). But there is a lack of empirical evidence of the relationships between the state of the core muscles and cycling performance, postural stability and the injury incidence rate. Abt et al. (2007) found that fatiguing trunk muscles have significant compensatory effect on cyclist movement kinematics without alterations in pedalling kinetics. This leads authors to suggestion that the core strength training improves torso stability on the saddle and this helps to maintain the alignment of the lower extremity for the more effective force transmission to the pedals (Abt et al., 2007). But the assumption that better core strength leads to more stable cycling position has a lack of empirical evidence.

The definition of core stability and methods to measure its status is object of wide discussion because of the complexity of this ability (Haugen et al., 2016). In a last decade the Functional Movement Screen (FMS) 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 et al., 2014). The FMS test includes 7 fundamental movement exercises that are evaluated in the terms of the quality of movement patterns, bilateral symmetry and existence of the compensatory movements in a scale from 0 to 3 with a maximal overall score of 21 points (Cook et al., 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 et al., 2007; Hotta et al., 2015). Validity of the FMS to predict sport performance and ability to perform sports specific movement correctly is not so clear as demonstrated with the risk of injuries (Kraus et al., 2014). There are findings that the core stability and FMS are not strong predictors of exercise performance (Okada et al., 2011), but there is evidence that athletes with high FMS score have better results in a longer time perspective, as less injuries disturb the training process (Chapman et al., 2014). Information about road cyclists FMS score level is not very well documented and also the validity of those tests to predict injury risk, sport specific movement patterns and performance in cycling is not known.

The purpose of this study was to characterise the changes in the power of the normalised ground reaction forces and COP swaying, as measures of the cycling stability and effectiveness of full body motion during an incremental cycling exercise; and to examine the relationships between cycling specific postural stability and cyclists ability to perform functional movements, measured by the FMS test.

MATERIALS AND METHODS

Participants

Participants of the current study included 38 competitive junior (n=10), U23 (n=24) and under 25 years old elite (n=4) class male road cyclists. The participants went through anthropometrical measurements (age 19.2±2.3 yrs., height 181.7±6.6 cm, body weight 74.3±7.3 kg, Vo2max 65.7±4.2 ml/min/kg), completed a health screening questionnaire and signed an informed consent term in accordance with the principles of the Declaration of Helsinki. All athletes had at least 5 years of focused endurance cycling training and competition experience, and had annual cycling distance above 12000 km during the last season and above 2000 km during preparation period before experiment. The participants were free of injuries and the study was conducted during the second half of preparation period of cycling season.

Instrumentation and procedures

All experimental procedures for one person were made on the same day and protocol consisted of 2 separate tests: Functional Movement Screen (FMS^{TM}) tests and incremental cycling exercise. All cyclists were familiar with named tests and had performed both tests at least one time in the past. The FMS test were performed after 15 minutes warm up in cycling ergometer and visual and verbal introduction of FMS test performing criteria's. The FMS consisted of the following sub-tests: deep squat (DS), hurdle step (HS), in-line lunge (ILL), active straight leg raise (ASLR), shoulder mobility test (SHM), rotary stability test (RS) and trunk stability push-up (TS), that assessing hip flexion, external and internal rotation strength and mobility, core stability and the mobility of shoulder joints (Cook et al., 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 directly to the computer by two HD web-cameras (frame rate 30 Hz).

Experimental cycling exercise was performed using the cyclist's personal racing bikes mounted on the cycling ergometer Cyclus 2 (Avantronic, Cyclus 2, Leipzig, Germany), which were fixed on two Kistler 9286B force plate. The Cyclus 2 ergometer 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 100 W and was followed by the incremental cycling exercise: target cadence 90±5 revolution/min (rpm), initial workload of 100 W and the workload increased by 25 W after every 2 minute until exhaustion. Exhaustion was defined as the point when the participant was no longer capable of maintaining a cadence of 70 rpm. The cycling tests were conducted in sitting position hands on the drops.

During and after 3 minute of the cycling exercise the heart rate and breath by breath pulmonary O2 (Vo2), CO2 production (Vco2), and expired minute ventilation (VE) 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.

Cycling specific postural stability was measured with two six component Kistler 9286B force plates (virtually combined surface of 0.6x1.4 m plate) connected rigidly with Cyclus2 ergometer supports– one plate was under the bicycle front fork support and the other plate was under the ergometer load unit, connected with bicycle rear fork. The ergometer weight was set to zero before the cyclist sat on the bicycle, therefore only riders mass was counted. During the incremental test all 16 analogue channels of two plates and 6 GRF components were captured by Kistler BioWare software with frequency of 200 hz: 3 linear components along mediolateral (Fx), anteroposterior (Fy) and vertical axis (Fz) relative to bicycle direction and 3 rotational moments (Mx, My, Mz) around those axis.

All data from Cyclus2 ergometer, Cosmed Quark CPET metabolic cart, and Kistler Force plates were synchronized in time and captured continuously.

Measures

Captured video of FMS tests were analysed with the video analysis software Kinovea 0.8.25 by an experienced (22 years of practice) physical therapist with 6 years of experience with the FMS. The movement quality of all 7 sub-test 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 items (hurdle step, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability test) were 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 score, resulting in a maximum of possible 21 points. (Cook et al., 2014a and 2014b).

The maximal aerobic peak power (PP) and ventilatory threshold levels assessments 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/Vo2 curve while the VE/Vco2 slope remains constant; the inflexion point between Vo2 and Vco2. The AnL was determined by the second nonlinear increase in VE and the second nonlinear increase in VE/Vo2 slope with simultaneous increase in VE/Vco2. The maximal aerobic oxygen uptake (VO2max) was determined as the highest 30 s average during the exercise. For the future analyses the AeL, AnL and PP power levels were determined as increments where the level moment was achieved. When the certain intensity level was achieved during first 30 sec of the incremental step the previous increment was chosen. Also the easy cycling intensity, described as 50% of PP was incorporated to future analysis.

The force plate data were exported from Kistler Bioware to C3D format and future signal processing and computations were performed with Visual3Dv6 (C-motion inc) software: all 16 force plates analogue signals were filtered with 20 Hz zero lag 4-th order Butterworth low pass filter to remove high frequency noise and the drift of all force components were corrected by previously collected reference values. After analogue signals correction the 6 ground reaction force (GRF) components (3 linear and 3 angular) and two-dimensional Centre of Pressure (COP) values were computed for one force structure (dimensions 0.6x1.4m) combined from 2 force plates. The 0 of coordination system was set under the bottom bracket of bicycle: the X-axis (mediolateral, ML) was perpendicular with bicycle with the direction from left to right; the Y-axis (anteroposterior, AP) was along with bicycle frame with the direction from rear to front and the Z-axis was directed vertically upward.

The average resultant COP sway velocity and standard deviation (SD) of 6 GRF (3 force and 3 moment) components and COP amplitudes over the 30 sec period during the middle of the second minute in 50% of PP, AeL, AnL and PP intensity levels were computed. To measure the postural stability effectiveness the SD values were normalised with intensity level powers in percent's (100*SD/Power).

Analysis

Statistical software SPSS version 23.0 (IBM company, New York) was used for data analysis. Descriptive statistics were computed for all variables and for every test phase and expressed mainly as a mean±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 cadence, COP placement and postural stability measures between analysed intensity levels of incremental exercise. Pearson product-moment (for normally distributed variables) or Spearman rank correlation (for non-normally distributed variables) was used to examine the relationship between postural stability measures and FMS score. Significance level for t-test and correlation tests was set at $p<0.05$. The effect magnitude for correlations was interpreted as moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and extremely large (0.9-1) (Hopkins, 2010).

RESULTS

Postural stability during incremental cycling exercise

The average power values of analysed cycling intensities for 50%PP, AeL, AnL and PP were accordingly: 174±18W (2.35±0.19 W/kg), 233±23 (3.15±0.28), 313±31 (4.22±0.29) and 363±32 (4.89±0.32). The average cadence during the test was 90.3±3.7 rpm and did not vary between intensity levels (89.9±3.0; 89.9±3.5; 90.5±3.8 and 90.8±3.7).

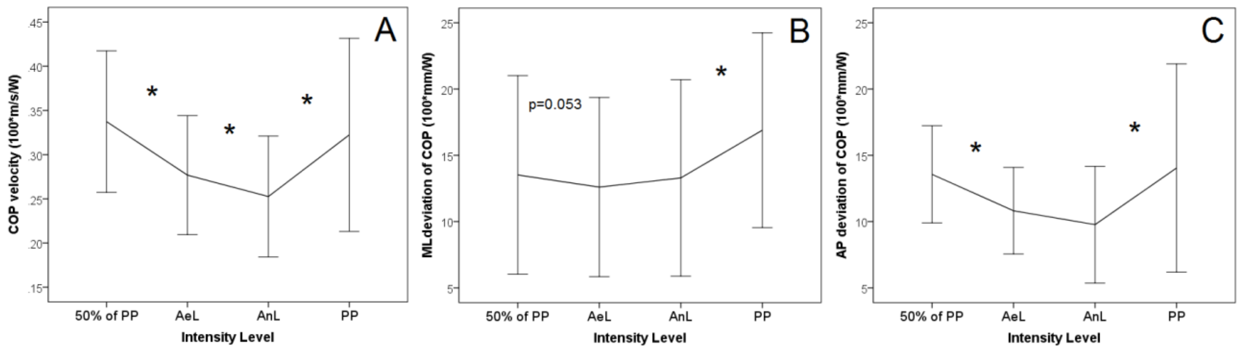

Figure 1. Dynamics of average (±SD) power normalised COP average velocity (Figure 1A) and COP position deviation along medio-lateral (ML) (Figure 1B), anterior-posterior (AP) (Figure 1C) direction during incremental cycling exercise (*- significant difference between intensity levels, $p<0.05$)

During the incremental cycling exercise the average position of COP were unaltered in mediolateral direction and also till AnL intensity in anteroposterior direction, but after AnL (35±26 mm from bottom bracket, BB) the COP average location shifted significantly forward to 54±39 mm from BB at PP level. The power normalized COP average velocity decreased significantly from 50%PP to AnL and after that increased again in PP level (Figure 1A). The relative sway of COP amplitude increased also after AnL significantly in AP and ML direction, no differences were found between AeL and AnL, but between 50%PP and AeL the power normalised sway amplitude had tendency to decrease in both directions (Figures 1B and 1C).

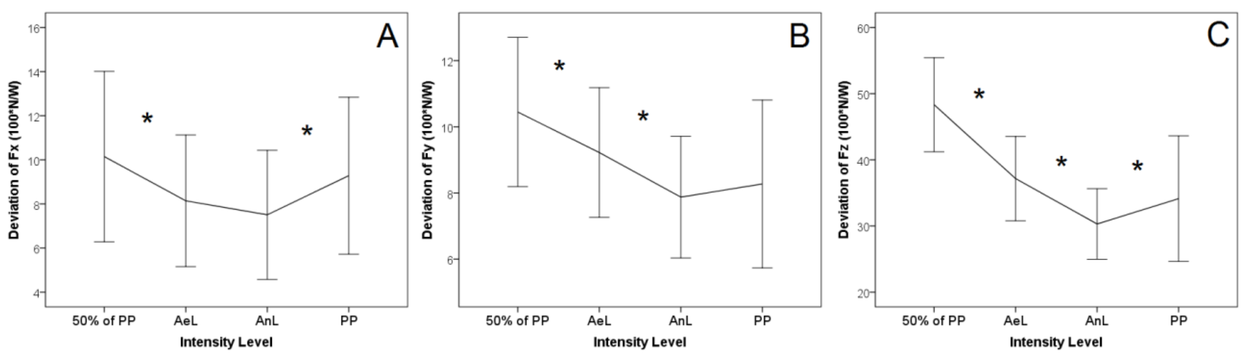

Figure 2. Dynamics of average (±SD) power normalised GRF linear components deviation along medio-lateral/Fx (Figure 2A), anterior-posterior/Fy (Figure 2B) and vertical/Fz direction (Figure 2C) during incremental cycling exercise (*- significant difference between intensity levels, $p<0.05$)

The responses of power normalised GRF components swaying were similar to findings in responses of COP components (Figures 2 and 3): from 50%PP to AeL all force and moment components swaying decreased relative to power output and same tendency exist significantly from intensity increase from AeL to AnL in AP and vertical Force and around vertical axis acting moment components. After AnL the most GRF components (Fx, Fz, Mx and My) deviations relative to power output increased, while AP (Fy) direction relative force sway remained unchanged and relative moment around vertical axel decreased significantly.

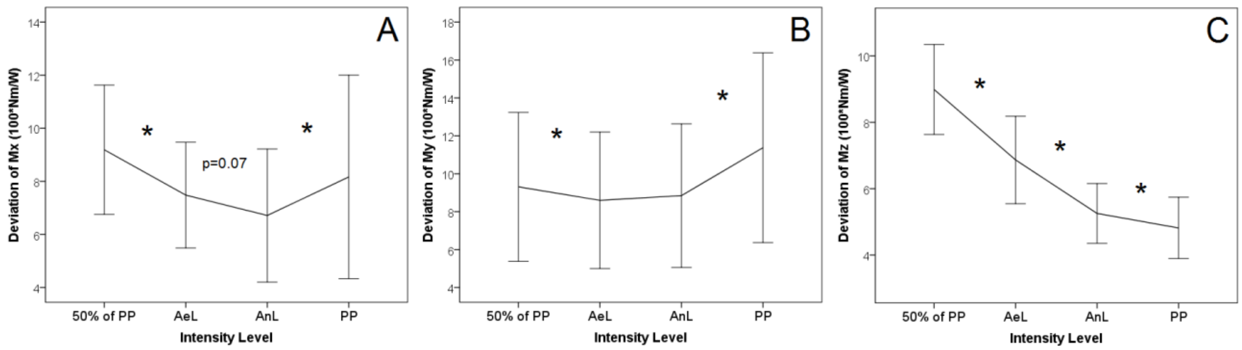

Figure 3. Dynamics of average (±SD) power normalised GRF rotational components deviation around sagittal/Mx (Figure 2A), frontal/My (Figure 2B) and vertical/Mz (Figure 2C) axis during incremental cycling (*- significant difference between intensity levels, $p<0.05$)

Table 1. The Correlations between COP and GRF components sway parameters.

N=38		Deviation of COP and Ground reaction force components							
		COP ML	COP AP	Fx	Fy	Fz	Mx	My	Mz
COP velocity	50% of PP	.706**	.657**	,249	,213	,113	.430**	.655**	,082
	AeL	.678**	.640**	.391*	,212	,287	.382*	.593**	,117
	AnL	.783**	.485**	.669**	.374*	.411*	,313	.701**	,110
	PP	.704**	.806**	.551**	.519**	.455**	.565**	.567**	.426**
MLdeviation of COP	50% of PP	1	,231	,024	-,071	-,180	-,001	.970**	-,155
	AeL	1	,107	,189	,093	-,233	-,114	.962**	-,248
	AnL	1	,048	.703**	,242	,020	-,099	.960**	-,069
	PP	1	.357*	.827**	,027	.435**	,049	.932**	.341*
AP deviation of COP	50% of PP	,231	1	.327*	,163	,293	.894**	,189	.425**
	AeL	,107	1	.391*	,183	.559**	.883**	,088	.482**
	AnL	,048	1	,220	.446**	.566**	.944**	,081	,236
	PP	.357*	1	,252	.592**	.477**	.818**	,292	,198

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

In table 1 are presented correlations between power normalised COP and GRF swaying measures, that present internal relationships of different postural stability components. The results show that most integrative postural stability measure is average COP velocity, which is significantly correlated with all other parameters in PP level and with most of parameters in lower intensity levels. In levels equal or lower than AnL the COP sway velocity is more related with ML movement of COP, but in PP level with the AP movement.

The relationship between cycling stability and cyclist's FMS score

The descriptive statistics of FMS test results are presented in table 2 and relationships between FMS score and postural stability measures in table 3. The most dominating FMS scores in cyclists were 15 points (achieved by 10 cyclists) and 16 points (9 cyclists), 16 cyclists had FMS score equal or lower than 14 points. Most demanding exercise for road cyclists was rotary stability test.

Table 2. The descriptive statistics of FMS test overall score and 7 sub-test results (DS - deep squat, HS - hurdle step, ILL - in-line lunge, ASLR - active straight leg raise, SHM - shoulder mobility test, RS - rotary stability test, TS - trunk stability push-up)

N=38	FMS Score	DS	HS	ILL	ASLR	SHM	RS	TS
Median	15	2	2	2	2	2	2	2
Mode	15	2	2	2	2	2	2	2
Mean	14,7	2,1	2,1	2,2	2,3	2,1	1,8	2,0
Std. Deviation	1,6	0,3	0,3	0,5	0,6	0,8	0,4	0,7
Minimum	12	2	2	1	1	1	1	1
Maximum	18	3	3	3	3	3	3	3

The FMS score had moderate to large negative correlations with power normalised COP sway velocity, ML COP and Moment sway around frontal axis (Table 3) in all intensity levels, but strongest correlations with FMS score had COP velocity, especially in higher intensity levels (Figure 4). The stronger relationships between FMS score and postural stability measures were found in AnL intensity.

Table 3. The Correlations between FMS test results and cycling stability measures.

N=38		COP velocity	Deviation of COP and force components							
			COP ML	COP AP	Fx	Fy	Fz	Mx	My	Mz
FMS Score	50% of PP	-.527**	-.468**	-,296	-,031	-,071	,004	-,183	-.444**	,011
	AeL	-.492**	-.566**	-,176	-,156	-,011	-,001	-,070	-.547**	,106
	AnL	-.652**	-.572**	-.380*	-.413**	-,138	-,206	-,286	-.557**	,002
	PP	-.580**	-.509**	-.463**	-.343*	-,266	-,293	-.321*	-.428**	-,139

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

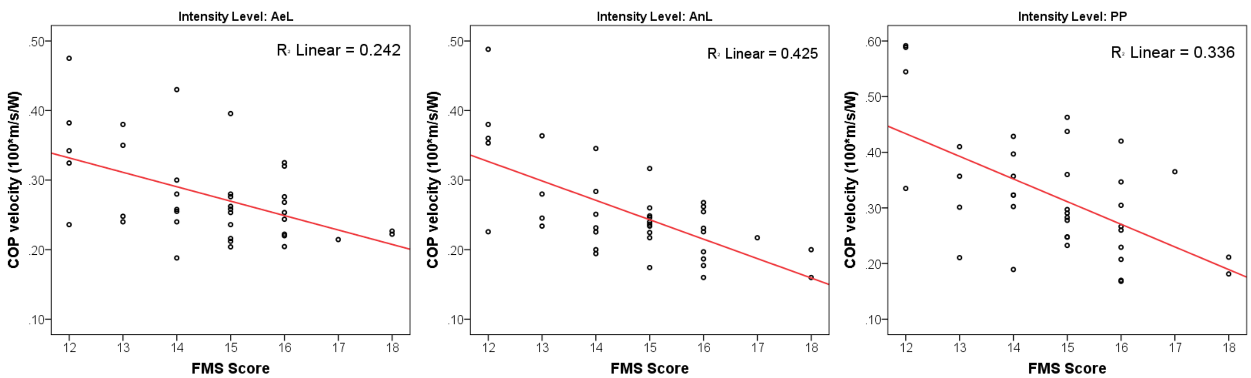

Figure 4. The relationship between power normalised COP sway velocity and cyclist's FMS score in AeL, AnL and PP intensity levels.

DISCUSSION

The first aim of present study was to evaluate the cycling specific postural stability measures and their dynamics during incremental seated cycling exercise conditions. The majority of pedalling stability related measures showed lowered trend of postural sway relatively to power output from low intensity to anaerobic threshold level that is consistent with similar trends of increased metabolic economy (Ettema & Lorås, 2009) and efficiency of pedalling force delivery (Bini et al., 2013) along with power increase. At same time the relative postural stability decreased significantly in peak power level and along with that also the average COP as a projection of body COM moved in average 19 mm forward. This means that cyclist moved forward toward the nose of the saddle that is a compensatory movement to increase the power output, but in same time the pedalling effectiveness may be reduced (Menard et al., 2016). The forward shift of COG means also that cyclist's body is less supported by saddle and more stabilisation from trunk muscles is needed to control the force on the axis from handlebars to the pedals. In combination with a low level of core muscle strength this situation can cause more movement of the upper body, supported by the findings of Costes et al. (2015) that along with the power increase of the acceleration forces directed to pelvis and upper body will increase. The most sensitive GRF variable to predict COM movement is COP sway velocity (Masani et al., 2014), that was also most integrative measure of cycling specific stability in our study.

The additional aim of present study was to analyse relationships between the cycling specific postural stability during pedalling at different intensity levels and FMS score that describes the cyclists' core stability and fundamental movement abilities in body control (Cook et al., 2014a). The results of FMS test indicated that less than half (n=16) of the cyclists achieved score of 14 points or less, that is found to be a line for elevated injury risk (Kiesel et al., 2007; Hotta et al., 2015). The moderate to strong relationships between cycling postural stability and FMS score directed also that cyclists with low core stability and pure ability to control his body are moving more in the saddle. More specifically the low scored cyclist had tendency of a more pronounced inclination and lateral movement of the bicycle at all intensity levels. In higher intensity levels the low FMS score were also related with larger anteroposterior COP movement and mediolateral force swaying. The previous studies have also found that during strenuous cycling exercise the anteroposterior direction seems to be a sensitive direction for stability decrease (Wiest et al., 2011). Most sensitive measure of the cycling stability according to cyclist's musculoskeletal state was the COP sway velocity that has been found to correlate strongly with acceleration of the body COM (Masani et al., 2014). The strongest correlations between postural stability measures and FMS score were found in anaerobic level, which is the highest physiological steady state level, where all body functional systems are optimised to work as rationality as possible. At the anaerobic level of work intensity the determination coefficient between FMS score and COP sway velocity was 0.425. This means that over the 40% of variation in COP sway velocity can be described with cyclists FMS score or core stability and functional movement's ability level. The named results of our study support the previous accounts of beneficial effect of the core stability training on the cycling specific stability (Abt et al., 2007; Fordham et al., 2004; Asplund & Ross, 2010).

Our study showed that usage of force plates can give valuable information about cycling-specific postural stability and global movement efficiency during pedalling actions at different workloads. Also was found that cycling stability analyse with force plates can detect intra individual effect in cyclist's musculoskeletal state. The future research can be directed to the relationships between cycling stability, metabolic economy and force delivery efficiency to pedals with aim to analyse effect of pedalling technique to postural stability or vice versa and evaluate the effect of postural stability to cycling economy. The force plates can be also used to study effects of different cycling positions, bicycle set-ups, pedalling cadence and training modalities to cycling stability.

CONCLUSSIONS

Results of the present study indicate that most integrative cycling specific posture stability measure is COP sway velocity that is also most sensitive predictor of cyclist's musculoskeletal state, measured by the FMS test. During an incremental cycling exercise the power normalised postural swaying decreased up to the intensity at the level of anaerobic threshold and during the level of the maximal aerobic power the postural stability decreased significantly.

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