LOWER SPINE LOADING AND PELVIC KINEMATICS THROUGHOUT A NEAR-MAXIMAL 10 KM RUN

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The purpose of the present study was to investigate the effects of fatigue on lower back loading and pelvis kinematics in distance running. Kinetic and kinematic data of the whole body was recorded for 13 subjects during a near-maximal 10-km run. Pelvis kinematics were calculated in 3D while moments acting on the lumbar spine were determined by using a full body lumbar spine model in OpenSim. We found significant effects of running distance for pelvis kinematics in the transverse and sagittal plane whereas the lumbar spine moments increased significantly in the frontal and transverse plane. These results support earlier findings suggesting a connection between running and spinal or pelvic overuse injuries. Thus, distance runners should focus on a controlled arm swing and upper body rotation as well as pelvis stabilization.

KEYWORDS: Running kinematics, back load, spinal curvature, spine, pelvic stability.

INTRODUCTION: Physical activity plays a crucial role in disease prevention and overall health. With an increasingly sedentary lifestyle, our society faces a crucial burden in (chronic) lower back pain (LBP) leading to disability and musculoskeletal disorders (e.g. Driscoll et al., 2014). At the same time, the positive health effects of regular running are the most important reason for people to start or continue running and they are well shown in the literature (e.g. Hespanhol Junior, Pillay, van Mechelen, & Verhagen, 2015). However, while the promotion of regular running definitely makes sense based on the physiological and epidemiological knowledge, from a biomechanical point of view distance running might put participants at risk for running related injuries and altered loads on the back. That is, knowledge of the biomechanical loads during running and the influence of fatigue is essential to evaluate benefits and potential harm of increased running activity in a society with prevalent LBP.
Running is a highly repetitive and complex movement leading to repeated impact loading of the runner's body. Thus, runners are prone to overuse injuries as these impact loadings must be attenuated at every ground contact. Although the lower back (i.e. lumbar spine) is in the center of the human skeleton and with that not exposed to the highest loads, studies identified connections between LBP and running. That is, despite the heterogenous cause of LBP (Brennan et al., 2006), earlier studies found a correlation between LBP and a reduced shock attenuation by the musculoskeletal system with increasing fatigue (Voloshin & Wosk, 1982) and suggested a propagation of shock waves to be a risk factor for the development of spinal injuries and degenerative changes in articular cartilage and joints (Collins & Whittle, 1989). More recent studies were able to confirm these findings (Mizrahi, Verbitsky, Isakov, & Daily, 2000). Other effects of fatigue on the trunk in running comprise an increase in trunk flexion, especially for less experienced runners, which might be attributed to fatigue in paraspinal and pelvic muscles like the M. gluteus maximus (e.g. Koblbauer, van Schooten, Verhagen, & van Dieën, 2014). Furthermore, Strohrmann, Harms, Kappeler-Setz, and Tröster (2012) showed an increase in vertical upper body rotation due to a suggested lack of pelvic stability. This connection of pelvic and lower spine findings might be explained by the amphiarthrotic iliosacral joint leading to a direct transfer of movements and loads of the pelvis to the lower spine, especially in the transverse and frontal plane.
Therefore, the purpose of the present study was to investigate the effects of fatigue on the loading of the lower spine as well as the pelvic kinematics during strenuous distance running. We hypothesized that the induced fatigue would provoke increasing moments between the vertebrae L4 and L5 (L4L5M) and changes in pelvic kinematics.

METHODS: We analyzed thirteen male recreational runners (age = 25.54 ± 2.76 years, height = 184.38 ± 4.81 cm, mass = 78.45 ± 8.12 kg) with an average 10 km personal best (PB) of 43:33 min:sec (± 7:28 min:sec). Verbal explanations of the experimental procedure were provided and the subjects gave written consent prior to testing. During the testing session the subjects ran 10 km wearing the Brooks Glycerin 10 (Brooks Sport Inc., Seattle, WA, USA) on an instrumented treadmill (Model 3DS, Treadmetrix, Park City, UT, USA) with running speed being set to the speed of 105% of their PB. That is, some extra time in regards to their PB was given for adjusting to the lab and the treadmill. A motion capture system with 13 cameras (Vicon, Oxford, UK) and the instrumented treadmill were used to measure and calculate the kinematics and kinetics of the subjects. The whole-body marker set of 90 reflective markers comprised nine markers on the spine (every second vertebrae from C7 to L5). During one testing run a total of six measurements (at start and every 2 km) were taken, each consisting of 15 right foot ground contacts. The kinematic and kinetic data was then used to utilize the Full-Body Lumbar Spine Model (Raabe & Chaudhari, 2016) in OpenSim (OpenSim 3.3, NCSRR, Stanford University, Stanford, California, USA) to calculate the L4L5M in all three dimensions through inverse kinematics and inverse dynamics. In addition, 3D pelvic kinematics were calculated in reference to the laboratory coordinate system. The statistical analysis consisted of a One Factor (running distance) repeated measures ANOVA with a significance level of $\alpha = 0.05$.

RESULTS: Tested speeds of 105 % of the subjects' personal best speed ensured the onset of running induced fatigue that continuously increased with increasing distance as shown by continuously high and increasing heart rate values (179.77 ± 10.86 bps) and high BORG scale rating at the end of the testing (17.77 ± 1.01). Table 1 shows the averaged minima (Min), means (Mean), maxima (Max) and initial range of motion (IniRom; i.e. change in pelvic angle from touch down (TD) to minimum) for all dimensions. Statistically significant results were found for the mean pelvis angle in the transverse plane and in the sagittal plane for the Min, Mean and IniROM pelvis angle (Table 1). Figure 1 shows the average 3D pelvic kinematics normalized to the stance phase.
For the L4L5M, statistically significant changes were found in the frontal plane for the Min and in the transverse plane for the Mean and the Max L4L5M (Table 1).

Table 1 Internal Minima (Min), Means (Mean), Maxima (Max), and Initial Range of Motion (IniROM) for all three axes and for all distances. Negative values equal a rotation towards the stance leg (frontal), towards the non-stance leg (transverse) and a flexion (sagittal). Statistically significant *p*-values are marked with *.

		0 km	2 km	4 km	6 km	8 km	10 km	
Parameter		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*p*-value
L4L5Moment, frontal	Min [Nm]	-36.54 ± 12.30	-37.42 ± 12.29	-37.33 ± 12.03	-39.32 ± 12.62	-40.42 ± 13.94	-42.46 ± 14.38	0.01*
L4L5Moment, frontal	Mean [Nm]	-17.55 ± 5.98	-17.50 ± 6.51	-17.42 ± 6.85	-17.35 ± 6.51	-18.16 ± 7.59	-18.33 ± 6.61	0.48
L4L5Moment, frontal	Max [Nm]	7.58 ± 8.95	7.34 ± 10.12	7.35 ± 11.04	8.47 ± 11.11	8.38 ± 10.43	8.89 ± 10.92	0.51
L4L5Moment, transversal	Min [Nm]	-30.45 ± 8.11	-30.60 ± 8.59	-29.85 ± 7.96	-29.90 ± 7.80	-30.02 ± 7.91	-30.21 ± 7.73	0.59
L4L5Moment, transversal	Mean [Nm]	-2.24 ± 3.62	-1.59 ± 3.60	-0.89 ± 3.41	-0.58 ± 3.52	-0.57 ± 3.26	0.60 ± 3.23	<0.01*
L4L5Moment, transversal	Max [Nm]	25.68 ± 6.59	26.50 ± 6.63	26.93 ± 7.09	27.48 ± 7.56	27.98 ± 6.85	26.93 ± 6.55	0.04*
L4L5Moment, sagittal	Min [Nm]	-17.30 ± 9.48	-18.07 ± 11.22	-17.33 ± 7.36	-16.30 ± 6.87	-16.04 ± 7.28	-15.82 ± 8.51	0.64
L4L5Moment, sagittal	Mean [Nm]	17.20 ± 7.15	18.18 ± 6.35	17.76 ± 6.15	18.39 ± 6.20	19.30 ± 6.79	18.37 ± 7.08	0.20
L4L5Moment, sagittal	Max [Nm]	42.57 ± 16.83	42.27 ± 13.26	41.99 ± 15.73	43.13 ± 14.96	45.32 ± 15.82	44.74 ± 15.25	0.32
Pelvis angle, frontal	Min [°]	-5.79 ± 3.10	-5.78 ± 3.08	-5.87 ± 3.16	-5.93 ± 3.04	-5.85 ± 3.08	-5.96 ± 3.27	0.83
Pelvis angle, frontal	Mean [°]	-2.27 ± 2.04	-2.23 ± 2.08	-2.30 ± 2.10	-2.33 ± 2.01	-2.22 ± 2.01	2.37 ± 2.18	0.81
Pelvis angle, frontal	IniROM[°]	-3.35 ± 1.98	-3.38 ± 2.02	-3.35 ± 2.11	-3.32 ± 2.07	-3.24 ± 2.01	-3.32 ± 1.95	0.61
Pelvis angle, transversal	Min [°]	-5.90 ± 3.48	-6.59 ± 3.66	-6.96 ± 3.49	-7.23 ± 3.37	-7.47 ± 3.25	-7.47 ± 3.58	<0.01*
Pelvis angle, transversal	Mean [°]	-2.90 ± 2.83	-3.43 ± 2.94	-3.72 ± 2.99	-3.95 ± 2.81	-4.15 ± 2.73	-4.16 ± 2.98	<0.01*
Pelvis angle, transversal	IniROM[°]	-4.70 ± 3.34	-4.85 ± 3.64	-4.78 ± 3.33	4.96 ± 3.19	-4.96 ± 3.18	-5.08 ± 2.98	<0.05*
Pelvis angle, sagittal	Min [°]	13.95 ± 4.56	14.09 ± 4.63	14.28 ± 4.78	13.90 ± 4.88	13.83 ± 4.82	13.84 ± 4.93	0.08
Pelvis angle, sagittal	Mean [°]	16.41 ± 4.58	16.48 ± 4.63	16.73 ± 4.73	16.38 ± 4.86	16.21 ± 4.90	16.28 ± 4.95	0.03*
Pelvis angle, sagittal	IniROM[°]	-2.90 ± 1.67	-2.88 ± 1.61	-2.88 ± 1.65	-2.80 ± 1.62	-2.73 ± 1.60	-2.79 ± 1.71	0.52

SD = Standard Deviation; Min = Minima; Max = Maxima; IniROM = Initial Range of Motion; * = statistically significant values ($p < 0.05$)

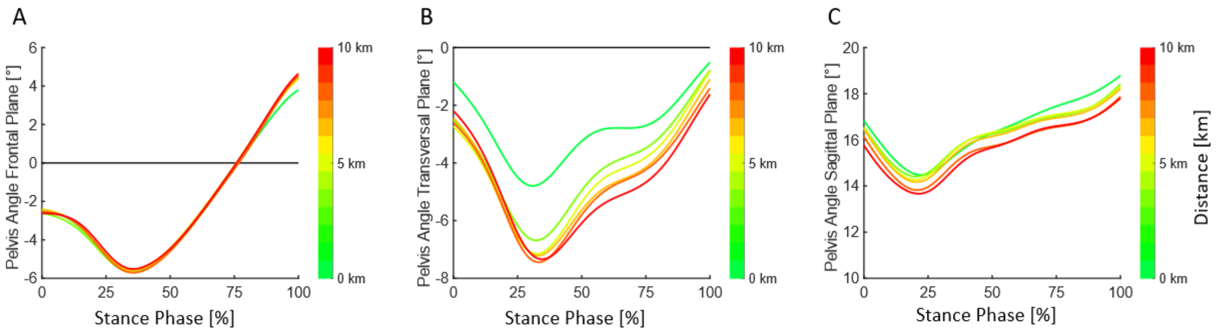

Figure 1 Average pelvic angle normalized to the stance phase for all three dimensions (A: frontal plane; B: transverse plane; C: sagittal plane).

DISCUSSION: The purpose of the present study was to investigate the effects of fatigue on lower back loading and pelvis kinematics in distance running. Our results show statistically significant increases in the amplitude of the frontal L4L5M which can be assumed to lead to increased loadings of the stabilizing muscles of both the lumbar spine and the pelvis. The highest measured frontal L4L5M in our data is 42.46 ± 14.38 Nm. Measuring the isometric strength of 27 healthy male subjects, McNeill, Warwick, Andersson, and Schultz (1980) found frontal L4L5M of approximately 150 Nm at the spine height of L5 and S1. Hence, although the moments acting a little higher at the spine (i.e. L4-L5 in our case) can be expected to be a little lower, these values show the frontal L4L5M in distance running to be far away from the isometric maximum moments that can be produced in isometric testing. Furthermore, Axler and McGill (1997) investigated the lower back loads about the vertebrae L4 and L5 during a variety of abdominal exercises finding a frontal L4L5M of 72 ± 13 Nm during an isometric side support or lateral plank.
In addition, our results show a significantly increased mean and maximal transverse L4L5M. This increase was also found by Strohrmann et al. (2012) and might be caused by a decrease in the muscles activation capacities and an impaired motor coordination leading to less controlled swinging of the upper body and arms and thus higher loads. The maximal transverse L4L5M in our measurements was 30.60 ± 8.59 Nm. Ng, Parnianpour, Richardson, and Kippers (2001) analyzed the maximal isometric transverse L4L5M for 23 healthy male subjects and found values of approximately 78 ± 22 Nm at the spine height of L5 and S1. Furthermore, Kumar (1997) found even higher isometric axial rotation torques of approximately 132 ± 41 Nm (peak) and 100 Nm ± 35 (average) in 27 young and healthy males.
Further research is needed to identify the effects of distance running on peak torque development of trunk muscles. With this knowledge it could be estimated whether the increases in trunk moments observed in this study might put runners at higher risk of sustaining overuse injuries.
Our results regarding the pelvis angle show a significantly increased mean vertical rotation as indicated by significant changes in all three parameters in the transverse plane and a backward tilt of the pelvis during stance phase as shown by for mean in the sagittal plane. Both might be explained by fatiguing stabilizing muscles (e.g. M. gluteus maximus) and can be assumed to lead to higher stress for the structures in the hips, the pelvis and the lumbar spine.

CONCLUSION: In summary, our results show altering effects of fatigue on lower back loading and pelvis kinematics in running. However, statistically significant effects do not automatically represent practically relevant findings. The comparison of our results with lower back loadings in other sports and the peak isometric force production in unfatigued states suggest that trunk muscle should be able to create the moments required for running in a fatigued state. However, overuse injuries caused by the repetitive occurrence of submaximal loads might be linked to running. During long distance running, athletes should focus on the swinging of the arms and the upper body rotation as well as stabilization of the pelvis. These movements should always happen in a controlled manner, especially towards the end of the running session, to avoid unnecessary and high transverse loadings of the spine and pelvis. Additionally, beginners should include enough rest time in between running sessions so that the body and especially the muscles of the back can recover ensuring sufficient spinal and pelvic stabilization.

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