BACK MUSCLE FATIGUE MIGHT LEAD TO ALTERNATED SPINE LOADING IN RECREATIONAL ERGOMETER ROWING

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The purpose of this study was to investigate fatigue related changes in spinal kinematics and muscle activity of back muscles during a 2000 m all-out performance on a rowing ergometer. Kinematic data of the trunk and EMG data of eight back muscles were recorded for ten subjects. A novel approach analyzing spinal curvature was utilized identifying a significant increase of up to 5 % ($p < 0.05$) for the thoracic spine. For the trapezius mean frequency was significantly decreased by up to 9 % ($p < 0.05$). The lumbar spine and erector spinae showed no significant changes ($p > 0.05$). These results contrast findings for elite rowers which might be explained by a different rowing technique. Increased spinal curvature is a factor for injury risk. Thus, rowing programs should include monitoring of spinal curvature and strengthening of stabilizing muscles.

KEYWORDS: Rowing kinematics, back load, back injury, spinal curvature, spine.

INTRODUCTION: Rowing, both on the water and on an ergometer, is a popular activity around the globe. With its combination of endurance, physical strength and motor coordination aspects it is a highly demanding activity (Hagerman, Hagerman, & Mickelson, 1979). Thus, it offers broad benefits for disease prevention and general health with at the same time only a low injury risk compared to contact sports.

Nonetheless, several studies report injuries in the context of rowing. For example, Smoljanovic et al. (2009) interviewed 398 rowers at the Junior World Rowing Championships in Beijing in 2007. Of the 393 reported injuries 290 (73.8%) were related to overuse and 103 (26.2%) were acute traumatic events. The area injured the most was the spine with 149 (37.9%) followed by the knee with 74 (18.8%). These areas are in accordance with other studies looking at the injury locations in rowing and the corresponding injury mechanisms (Hosea & Hannafin, 2012; Howell, 1984).

The rowing stroke is a repetitive motion putting a high load on the human body. In the process of transferring the power generated by the legs through the arms to the handle, the back functions as the connecting element and the cantilever. During this motion, the spine is loaded with compressive forces of up to 7 times body weight (Hosea & Hannafin, 2012) in a highly flexed position leading to high moments acting on the back. Adams & Dolan (1995) showed maximal or excessive flexion of the lumbar spine to increase the stress on passive structures. To compensate for these flexion moments, the active structures (i.e. muscles) must produce extension moments to protect the passive structures (i.e. vertebrae, intervertebral discs, ligaments) from damage. However, the back extensor muscles were shown to fatigue during a strenuous rowing performance suggesting an influence on the increased flexion of the lumbar spine (Caldwell, McNair, & Williams, 2003) and with that a higher injury risk.

Therefore, the purpose of this study was to investigate fatigue related changes in spinal kinematics and muscle activity of back muscles (i.e. erector spinae, latissimus dorsi, deltoideus posterior, trapezius descendens) during a 2000 m all-out rowing performance using a novel kinematic method to describe spine curvature.

METHODS: For this study the subject group consisted of ten male sporty and active subjects (79.10 ±12.66 kg; 181.20 ±9.94 cm) aged between 23 and 35 years (29.20 ±4.36 years). Verbal explanations of the experimental procedure were provided and the subjects gave written consent prior to testing. All subjects were experienced on the rowing ergometer and knew at least the basic rowing technique. No current history of low back pain was reported.

The testing was conducted on a Concept2 Model C ergometer (Concept2, Morrisville, Vermont, USA) and a 2000 m all-out approach was chosen to imitate a race performance on the Olympic distance. This approach reflects the duration, intensity and racing strategy of a competitive race (Mahler et al., 1984). During the trial all rowers were verbally encouraged and constantly updated on their rowed distance, rowing frequency and pace. Right before and right after the 2000 m all-out trial, three maximum rowing pulls were conducted to compare those values as a measure of exhaustion. The force of these maximal force pulls before and after the trial as well as the forces for every rowing stroke during the trial were measured by a strain gauge installed between handlebar and the chain of the rowing ergometer.

The marker set of 49 reflective markers focused on the upper body and spinal area. For the whole 2000 m race, motion analysis recordings (Vicon, Oxford, UK) of ten consecutive rowing strokes were recorded at every 250 m step. At 0 and 2000 m, the first and respectively last ten rowing strokes were recorded. We reduced the complexity to a 2D-model looking at only the sagittal plane, i.e. spinal flexion and extension moments as well as the sagittal curvature. The line of action for the measured force was determined by a first marker on the center of the air resistance wheel and a second marker calculated for the center of the handlebar. The force measured by the strain gauge was then applied on the rowers' shoulder joint that was calculated as three centimetres below the Acromion markers. The moments acting on the vertebrae were then estimated by the lever arm of the respective vertebra to the applied force. We calculated these moments under the assumptions of neglectable effects of body inertia or gravity. For the spinal curvature, the data of the vertebrae markers (every second vertebra from C7 to L5) was used to model the spine as a 4^{th} order polynomial function normalized to 201 data points. For simplicity reasons, the statistical analysis of the moments and the curvature was limited to ten heights of the spine (i.e. 0% height at L5 to 100% height at C7).

The EMG focused on eight muscles controlling and performing the rowing stroke. After shaving and cleaning the specific areas with alcohol, the surface electrodes were placed on the left and right erector spinae, latissimus dorsi, trapezius descendens and deltoideus posterior. The data was band-pass filtered (Butterworth, 10-500 Hz) to allow for analysis of the muscle activity. Furthermore, root mean square (RMS) values as well as the mean frequency (MNF) of the EMG data was examined for the entire stroke following the procedure explained by De Luca (1997) as a measure of muscle fatigue. The statistical analysis consisted of a One Factor Repeated Measures ANOVA (Distance) with an alpha level of 0.05.

RESULTS: The averaged maximum pull force outputs significantly decreased by 14% from 1182 N in the pre-test to 1016 N in the post-test ($p < 0.01$) while the BORG scale increased from an average of 7.7 right before to 19.6 right after the testing. In the data from our ten subjects we found different rowing techniques and movement patterns. Figure 1 shows a comparison of two subjects regarding their spinal curvature. Despite these individual differences we found significant main effects for rowing distance. The curvature increased significantly ($p < 0.05$) for 50%, 60% and 70% spine height (i.e. vertebrae Th6 to Th11) with no significant changes at other spinal heights. The largest change in curvature was observed at 60% spine height (i.e. Th8 and Th9). Figure 2 shows the peak moment and the peak curvature at this height as well as the RMS and the MNF of the trapezius descendens, because it stabilizes the thoracic spine at this height. In general, the peak moments showed a decreasing trend during the performance before increasing back to the initial values for the final 500 m (see Figure 2). Significant ($p < 0.05$) changes were found at 90% (i.e. Th2) with no significant changes at the other heights of the spine ($p > 0.05$). The amplitude of the EMG data revealed no significant changes ($p > 0.05$) in the RMS for all muscles. However, the frequency analysis showed significant decreases ($p < 0.05$) in the MNF on both sides for the latissimus dorsi, the trapezius descendens and the deltoideus posterior. No significant changes were found for the erector spinae ($p > 0.05$).

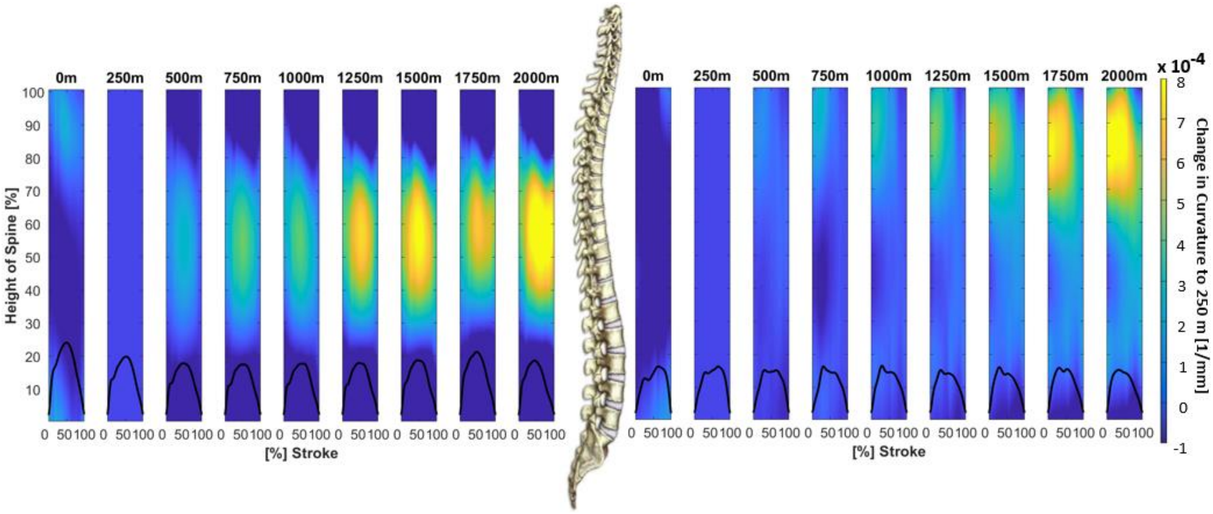

Figure 1: Changes in curvature for two different subjects.

Figure 1 shows the means of ten consecutive strokes. The top x-axis shows the rowed distance (0 to 2000 m) and the bottom x-axis the stroke phase. The black graphs on the bottom represent the force values and serve as indication for the stroke phase. The y-axis shows the height of the spine. All nine measurements are expressed as the difference to the 250 m values. More bright and yellow areas indicate a higher value for the change of curvature in that area as shown by the colormap on the right.

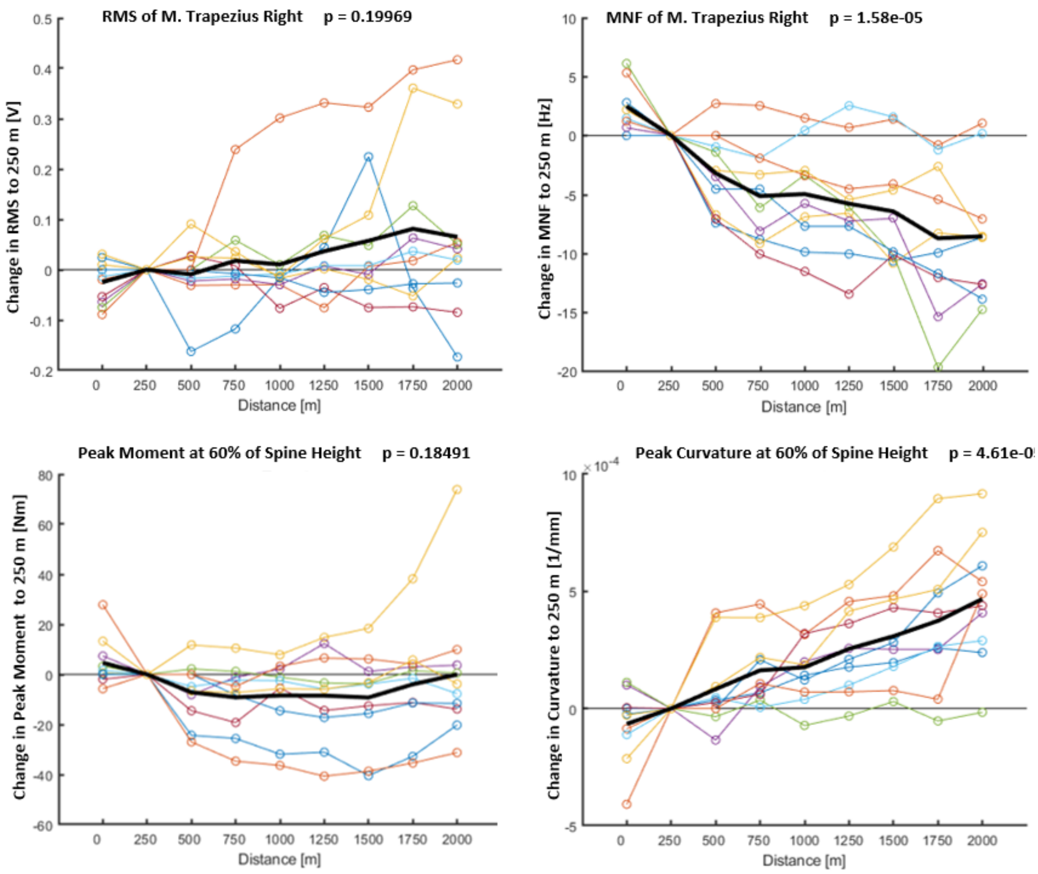

Figure 2: RMS and MNF of trapezius right (top), peak moment and peak curvature at 60% spine height (bottom).

The graphs in Figure 2 show the average of ten consecutive rowing strokes for all nine measurements for all ten subjects. The thicker black graph represents the mean of all subjects. Data are normalized to values of the 250 m-measurement as the first measurement is special due to the start and the first extra powerful strokes.

DISCUSSION: Scientific work investigating the spinal load and the role of the back muscles in rowing is rare. More knowledge of kinematics and muscle activity around the spine, especially in the presence of fatigue, could aid injury prevention and technique optimization.
We used a new approach of investigating the curvature of the whole spine instead of looking at the spine as a connection of only two or three segments. Thus, it was difficult to compare our findings with those from former studies. We hypothesized a higher curvature to occur when the stabilizing muscles fatigued. This increased curvature then might lead to higher loadings and injury of the passive structures. We found indicators for overall body fatigue (decreased maximum pulls, increased BORG scale) and specific fatigue in rowing related muscles (decreased MNFs). However, in contrast to Caldwell et al. (2003), the erector spinae showed no significant decrease in MNF. This might be due to our subjects not being trained rowing experts. They might be rowing with a different, less efficient rowing technique using less lower spine flexion and extension. Thus, erector spinae would fatigue less, which might lead to no or smaller changes in the curvature of the lower spine as found in our data. The significant increase in curvature for the thoracic spine can be hypothesized to be connected to the fatigued trapezius descendens. This increased curvature might lead to an unbalanced loading of intervertebral discs and with that to a higher injury risk. A limitation of this study is the use of a regular Fast Fourier Transformation over the whole stroke phase. Future studies should rather include time-frequency approaches.

CONCLUSION: Our findings showed that a strenuous rowing performance leads to changes in spinal kinematics and muscle activity of back muscles. On the one hand, the decrease in the MNF of the trapezius descendens might explain the increase of curvature in the thoracic spine. This change might lead to higher injury risk. On the other hand, the MNF of the erector spinae and the curvature in the lumbar spine showed no significant difference. This might be explained by the inefficient rowing technique used by our less experienced subjects. Thus, our findings might be more relevant for amateur rowers and their training program. For athletes and coaches the main conclusions are a focus on strengthening the spine stabilizing muscles as well as controlling the rowing technique and especially the spinal curvature. Here, development of simple body worn feedback devices should be promoted.
In the future, studies should focus on applying our experimental design to professional rowers to analyse their technique and performance. Furthermore, increasing the complexity and investigating the frontal plane regarding scoliosis and other effects appears beneficial.

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