MECHANICAL LOADING OF THE LUMBAR SPINE OF ELITE ROWERS WHILE ROWING FIXED AND SLIDING ERGOMETERS

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Low back injury is common in rowers. This study compared compressive forces of the lumbar spine, while rowing on fixed and sliding ergometers. Fifteen elite male rowers with no history of serious low back injury rowed the Concept2 Fixed (C2F), Concept2 Sliding (C2S) and RowPerfect (RP) ergometers at 32 strokes/min while 3D motion and external force data were recorded. Inverse dynamics analysis was used to find net lumbar moment and a lumbar model used to model compressive forces acting at L4/L5. Compressive force was significantly larger on C2F, at the catch and for 45 % of the stroke. Rowing on the C2F ergometer places greater compressive stress on the lumbar spine.

KEY WORDS: biomechanics, ergometry, rowing, L4/L5 compressive forces.

INTRODUCTION: Rowing is a physically and technically demanding skill that requires the back to act as a transfer for large forces between the upper and lower extremities (Hagerman, 1984). It is characterised by long distance aerobic training sessions which comprise 90 % of training volume and it is considered that the majority of rowing injuries are related to overuse. The most common type of injury in elite male rowers is the lower back (Hickey et al., 1997). About half of specific events causing rowing injuries occur off water.

On a fixed ergometer, the rower is positioned on a sliding seat and during the drive phase the rower is required to accelerate the entire body mass away from a stationary foot stretcher-flywheel complex. In addition to a sliding seat, the sliding ergometer has a foot stretcher-flywheel complex that is mounted on a slide. This allows a transfer of momentum between the rower and the sliding complex.

It is the aim of this study to estimate the spinal compressive forces in elite rowers while using Concept2 Fixed (C2F), Concept2 Sliding (C2S) and Rowperfect (RP) rowing ergometers. It is hypothesised that due to increased acceleration requirements, lumbar compressive forces will be greater when rowing on the C2F, compared to C2S and RP during the drive phase.

METHODS: Subjects: Fifteen injury-free elite male rowers volunteered to participate in this study. Their mean (± SD) age was 25.2 ± 4.4 years, height 1.915 ± 0.072 m and body mass 91.0 ± 7.4 kg. The Human Ethics Review Committee of the University of Sydney approved this study.

Experimental Design: The experiment was a multivariate repeated measures design with two within subject factors: ergometer (three levels: C2F, C2S, RP) and stroke (10 levels: 10 strokes); and one primary (catch lumbar compressive force) and three secondary (trunk acceleration, trunk-pelvis angle and stroke rate) dependent variables. The order of ergometer presentation was balanced to reduce carry over effects.

Rowers were asked to warm up for 5 min then perform 1 min rowing at at 80 % maximal propulsive power at 32 strokes/min, with a 1 min rest period between stroke rate trials. A rest period of 5 min was given between ergometer conditions.

Force data collection: Two new foot stretchers were constructed, each fitted with two 3D force transducers (Model 9067, Kistler Instrument Corp., AG Winterthur, Switzerland). A strain gauge (Model TLL-500, Transducer Techniques Inc., CA, USA) was connected in series at the chain-handle attachment.

Kinematic data collection: Fifty two markers were placed for an initial static trial with 12 of these being removed for the following rowing trials. The 3D trajectories of the joint centers were then calculated for each rowing trial. Nine video cameras and the force transducers provided input for the motion analysis system (EvaRT, Motion Analysis Corporation, USA) at 60 Hz.

Inverse dynamics modelling: The kinematics of the anatomical markers were recorded in 3D to provide more accurate joint center data for the sagittal plane model of the rower. Using a two-dimensional nine-segment whole-body model, the net joint forces and moments were calculated in a custom program. The spectra of position and force data were analysed to determine optimum cutoff frequencies (5 Hz for position and 10 Hz for force data) according to the method of Giakas and Baltzopoulos (1997).

Spinal modelling: The current study used a sagittal model of the lumbar spine to partition trunk forces and moments into extensor muscle force and resultant bone-on-bone force at L4/L5.

Analysis of results: Ten full strokes were analysed from each rowing trial. Each stroke was normalised to 100 % stroke. Ensemble force-time stroke profiles represent the mean of all subjects for one condition and 95 % confidence intervals were included to indicate variability across subjects.

Statistical analysis: Multivariate analysis of variance with repeated measures (SPSS for Windows, SPSS Inc., USA) was used to test the significance of any observed differences in the means. A Bonferroni adjustment was made for pairwise comparisons and multiple dependent variables. Differences were considered significant for continuous data if the mean was outside the 95% confidence interval for more than five consecutive data points.

RESULTS: The ten strokes analyzed within a trial were consistent. There was no effect of stroke on any of the tested variables or interaction with ergometer or stroke rate. The strokes rate across subjects did not differ by more than 1% of the required stroke rate.

Lumbar compressive forces: Compressive force was high at the catch and during early drive phase, increasing to reach a peak at mid drive phase (Figure 1.). The C2F curve shows compressive force on the fixed ergometer to be significantly greater than the two sliding ergometers during early drive phase (0 - 13 % stroke) and again in recovery (from 66 - 100 % stroke) ($p > 0.05$).

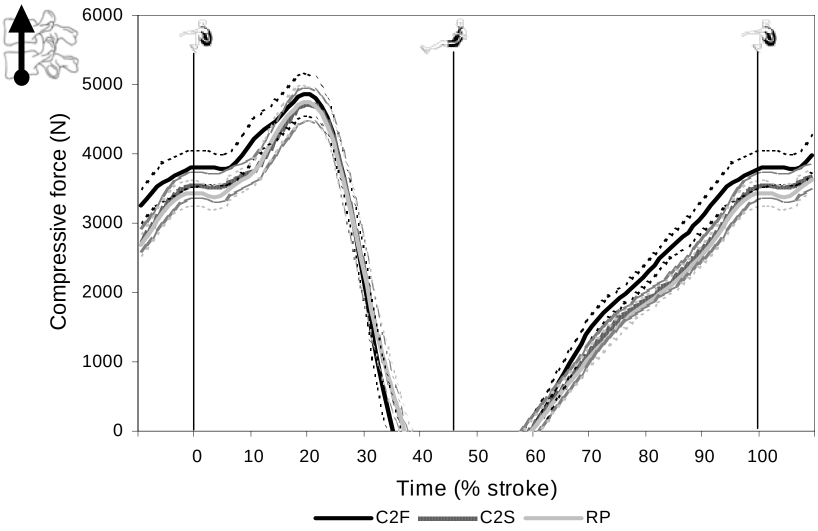

Figure 1. Stroke profile of mean compressive force.

Lumbar compressive forces at the catch: Lumbar compressive force at the catch was significantly different between all ergometer conditions ($p < 0.001$) (Table 1). C2F produced the largest compressive force at the catch, followed by C2S and RP produced the least. Effect size for interaction due to ergometer was large and differences in means ranged from 150 N (C2F *vs* C2S) to 435 N (C2F *vs* RP). Compressive force at the catch on C2F was 77 % of compressive force at maximum and slightly less (~ 70 %) for both the sliding ergometers.

Table 1. Mean and SD for Catch Lumbar Compressive Force and Stroke Rate, comparisons between ergometer conditions, power and effect size.

C2F	C2S	RP	Pair	Sig.	For the effect of ergometer	
					Power	**Effect size**
Catch Lumbar Compressive Force						
3670±114	3380±88	3220±78	C2F *vs* RP	0.000	1.000	0.818
Stroke Rate						
31.6±0.22	32.2±0.20	32.0±0.23	C2F *vs* RP	0.003		

Trunk acceleration: The two sliding ergometers have very similar trunk acceleration profiles (Figure 2.). The C2F has much greater trunk acceleration when compared to the RP and C2S ergometers. C2F trunk acceleration ranges from a negative peak in early drive phase of – 7.9 m·s^{-2}, to a positive peak in late drive phase of 7.3 m·s^{-2}, a range of 15.2 m·s^{-2}. Both the sliding ergometers require much less trunk acceleration, a range of 9.2 m·s^{-2} (– 5.6 - 3.6 m·s^{-2}, which represents about 60 % of C2F range).

Trunk-pelvis angle: There was substantial variability between subjects as indicated by large 95 % confidence intervals for the ensemble mean trunk-pelvis stroke profile. When trunk-pelvis angle profiles were considered for individual subjects the most consistent feature was an increased flexion from ~ 20 - 30 % of the stroke. Slight observable differences in trunk-pelvis angle between ergometers occurred during late recovery, at the catch and early drive phase. At this time the C2F ergometer produced a smaller trunk-pelvis angle compared to both the sliding ergometers (Figure 3).

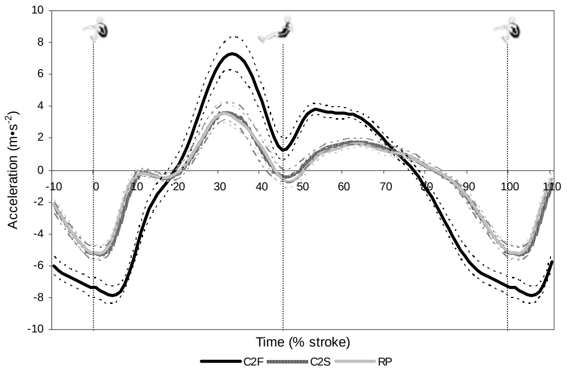

Figure 2. Stroke profile of horizontal acceleration of trunk segment COG.

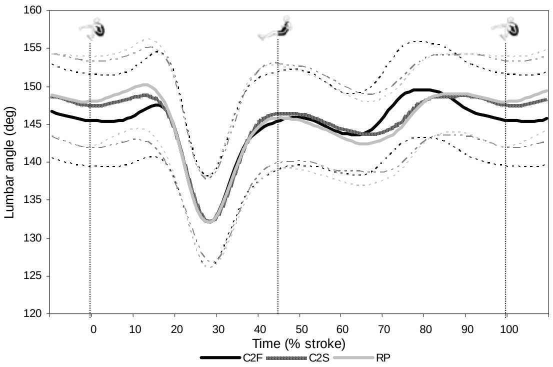

Figure 3. Ensemble mean trunk-pelvis angle at race pace

Mean trunk-pelvis angle at the catch was ~ 146° on C2F and ~ 148° on both C2S and RP. Trunk-pelvis angles at the catch were generally greater than at the time of maximum spinal force production (corresponds to 22 % of stroke).

DISCUSSION: Compressive forces: Compressive force profiles, for the fixed and both the sliding ergometer conditions, indicate that the lumbar spine is under considerable stress during ergometer rowing. The C2F ergometer produced consistently larger compressive forces at the catch, when compared to the C2S and RP ergometers.

Differences in lumbar stress between the fixed and sliding ergometers at the catch cannot be attributed to differences in handle force as the handle force is zero at the catch. When no force is applied to the handle, the force produced by the rower is used only to accelerate the stretcher complex and the body mass (in opposite directions). As the stretcher is stationary on the fixed ergometer, all force produced by the rower at the catch is used to accelerate the rower COG. In comparison to the sliding ergometers, the C2F exhibits far greater horizontal trunk acceleration at the catch. As the handle force is zero, the net lumbar moment at the catch is determined largely by the required acceleration of the trunk, head and arms. Therefore, at the catch, the significantly larger compressive forces produced are the result of the larger body mass acceleration requirements of the fixed ergometer.

Risks of injuries: Mean maximum compressive forces exceeded the NIOSH manual handling recommendations for safe lifting (3400 N) during all ergometer conditions. The vertebral body is the most likely to be injured by a purely compressive load and this recommended maximum compressive force is based on cadaver experiments of vertebral breaking limits. However, this limit considers only static lifting situations. For the trunk, rowing can be considered as a repetitive, dynamic, flexion-extension movement. Repetitive dynamic movements, with large compressive force components, may place structures other than just the vertebral body at risk of injury.

Trunk-pelvis angle: The absolute angles of the trunk and pelvis segments followed similar trends of extension during the drive phase. It seems that despite individual anatomical and technical variability, there are several observations regarding technique. A posture at the catch of increased anterior rotation of the pelvis may help reduce stress on the lumbar spine. During the drive phase, a moderately flexed lumbar posture may be suited to optimal compressive force resistance and technical effectiveness.

CONCLUSION: At the catch, rowing on the C2F ergometer produced consistently larger compressive loading of the lumbar spine, compared to the C2S and RP ergometers. This was due to the large body acceleration requirements of the stroke while rowing on the fixed ergometer. It is possible that these elite male rowers have found a safe posture for the lumbar spine at the time of maximum compressive loading.

At the catch, differences in compressive forces can be attributed to the effects of upper body acceleration which, in turn, depend on the ratio of body mass to ergometer/fan assembly mass. Even greater differences may be obtained if the mass of the instrumentation for the stretcher could be reduced.

While these results emphasize the significant mechanical stress on the lower back during ergometer rowing, similar research is needed during on-water rowing.

REFERENCES:

Giakis, G. and V. Baltzopoulos. Optimal digital filtering requires a different cut-off frequency strategy for the determination of the higher derivatives. *J. Biomech.* 30:851-855, 1997.

Hagerman, F. C. Applied physiology of rowing. *Sports Med.* 1:303-326, 1984.

Hickey, G. J., P. A. Fricker, and W. A. McDonald. Injuries to elite rowers over a 10-yr period. *Med. Sci. Sports Exerc.* 29:1567-1572, 1997.

Acknowledgements

Floren Colloud was granted by a *Bourse Lavoisier* from the French Foreign Office.

We wish to thank the subjects who gave their time and effort to participate as well as coaches of NSWIS, Sydney Uni Boat Club and UTS Haberfield for helping with recruiting subjects. Thanks to Ray Patton for his technical assistance throughout this project.