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Title: Measuring Spinal Motion in Rowers:
the use of an electromagnetic device

Authors: Anthony M J Bull PhD, Alison H McGregor PhD

Where the work was performed: BioDynamics Research Group
Imperial College, London, U.K.

Corresponding Author: Dr Anthony M J Bull
Department of Biological and Medical Systems
Imperial College
London SW7 2BX
U.K.
Tel: +44 20 7589 5111 ext 57101
Fax: +44 870 125 4985
Email: a.bull@ic.ac.uk

Running Title: Spinal Motion of Rowers

Abstract

Objective. To determine whether a skin-mounted electromagnetic measurement device can be used to measure lumbar spinal motion in rowers and discriminate between variations in technique.

Design. The lumbar spinal kinematics of elite level rowers were assessed with an electromagnetic device during ergometer training using five technique variants (Flock of Birds™, Ascension Technology, Burlington, Vt, USA). The system was correlated with sagittal MRI imaging of the lumbar spine and pelvis.

Background. Rowing technique is related to performance and injury. This study sought to test a method to obtain quantitative data on the effect of changes in technique on lumbar spinal and pelvic motion.

Methods. Lumbar spinal and pelvic motion were measured in six elite level rowers on an ergometer using normal rowing technique, three common bad technique variants, and after a ten minute piece of rowing simulating fatigue.

Results. Significant differences were found between the different rowing techniques for femoral, thoraco-lumbar and lumbo-sacral flexion.

Conclusions. Kinematic parameters of spinal motion of rowers can be measured dynamically and used to quantify and discriminate between good and bad rowing styles.

Relevance

There is a consistent style of “good” rowing technique on an ergometer. Deviations from this technique can be measured and this will allow studies to be conducted comparing rowing styles between rowers of different standards and between different boat houses. There is potential to develop a dynamic feedback system to the rower that will assist in training and eradicate bad technique variants.

Key words: rowing, lumbar spine, motion analysis, electromagnetic device.

Introduction

Rowing is a strenuous sport with a significant lumbar spinal injury rate amongst competitive participants of all standards. It has been speculated that the majority of spinal injuries are mechanical in origin and related to the training regime and rowing technique¹. Biomechanical and especially kinesiological investigations into the mechanical efficiency of rowers are rare and there is a limited understanding of the movement of the trunk and body segments, particularly the spine, during rowing. The recent introduction of a new rowing technique, which emphasises the drive off the legs, may impact spinal loading. Detailed kinesiological investigation of the movement of the lumbar spine and pelvis during rowing will provide an insight into the current trend of increased low back pain amongst rowers. This will lead to improved understanding of the mechanics of rowing. improved understanding of the mechanics of rowing. Once the components of an effective and “safe” rowing action have been defined, biofeedback principles can be employed to teach and augment the rowing action of developing and novice rowers, and to facilitate return to sport of rowers injured through poor technique.

The objective of this study was to identify and develop a technique to measure the lumbar spinal motion of rowers in order to characterise good and bad rowing technique.

Methods

Subjects

Ethical approval for this study was obtained from Riverside Research Ethics Committee. Six elite national level male rowers (age: 20-21 years, height: 1.82-1.96m, weight: 79-94 kg) were recruited from the top squad rowing team at Imperial College Boat Club and written consent obtained. None had previous or current history of low back pain. Six additional male rowers recruited from the same boat club participated in the MRI assessment of the

measurement technique (age: 23-30 years, height: 1.80-1.95m, weight 78-100 kg).

Electromagnetic motion measurement equipment

The motion measurement equipment used is an electromagnetic device that can measure the position and orientation of up to 30 receivers relative to a transmitter (Flock of Birds™, Ascension Technology, Burlington, Vt, USA). Each receiver is connected by a long cable to a control unit, which is, in turn, connected to a personal computer for data acquisition. The device has an accuracy of 0.23% of the step size for translations and 1.8% of the step size for rotations when used within an optimal operational zone of minimal error for which the transmitter to receiver separation is between 271 and 723 mm. To ensure a stable representation of the receiver orientation at high elevation angles, the rotation matrix output mode was used.² This corresponds to a 1° error for a rotation of 60°, which is the maximum relative rotation of a single body segment in this study. Non-ferromagnetic materials have no effect on the accuracy, and mild steel has no effect when positioned more than 150mm from both the receivers and transmitters. These data were obtained in the authors' laboratory.² There is no evidence of drift. Receivers have dimensions 30x20x32mm.

Mounting blocks were designed to allow press-fit fixation of the receivers to the anatomical landmarks. These blocks were firmly fixed to the skin using double-sided tape. One mounting block was fixed to the twelfth thoracic spinous process overlying the thoraco-lumbar junction. This was chosen, because the 12th thoracic spinous process was an easy landmark to find and we did not expect much hinging to occur at this level. The second sensor was fixed on the sacrum just below the lumbo-sacral junction. A third receiver was fixed to the femur, by strapping a splint to the thigh and securing the receiver to the splint. A second splint was attached to the contralateral thigh, so that the rower experienced no sensation of imbalance. This permitted the determination of the angle of each body segment (Figure 1).

All the mounting blocks were positioned by the same investigator. Once the receivers were fixed to the mounting blocks, the cables connecting the spinal receivers to the control units were taped over the left shoulder of the subject. The transmitter was positioned so that the device was used within the zone of minimal error without any ferromagnetic objects within 150 mm of the device. The receivers were zeroed with the subject sitting upright on the ergometer with his feet on the floor (Figure 1). The data from the electromagnetic measurement device were recorded at 20 Hz sample rate using custom-written software.

Testing Procedure

The rowers were asked to warm up and row on the ergometer using their normal rowing style. The rowers reported no change in their technique as a result of the equipment. Marker positioning was checked to identify if any slipping or loss of adhesion had occurred and recording commenced at the subject's "normal" rowing pace at a sample rate of 20 Hz for three strokes. Further recordings of rowing technique were made at the start and the end of a ten-minute maximum output training session on the ergometer (a 'ten-minute piece'). In addition, after a period of recovery subjects were asked to simulate three poor rowing technique variants. These were 'bum-shoving', 'taking the catch with the shoulders', and 'leaning back too far'. Data were recorded when the rower felt they had achieved the required rowing style.

MRI evaluation

This evaluation was conducted to quantify the relative motion between the receiver mounting blocks and the spine, a measure of the skin movement relative to the underlying bone. A custom-designed device was built to allow the spinal position of rowers to be set at different stages of the rowing stroke in an interventional MR scanner. This interventional MR scanner

(General Electric Signa SP10, Milwaukee, USA) is unique in that it consists of 2 connected but opposing ring “doughnut” magnets, with a 56 cm gap between them generating a uniform field of 0.5 Tesla. The custom built device was placed between this gap allowing the rowers to assume different rowing positions within the stroke³. The mounting blocks were positioned on the rowers at the two spinal locations, with MR markers (castor oil tablets) fixed to the mounting blocks. The lumbar spine and pelvis were imaged in the sagittal plane through the midpoint of the spinous processes at the two extremes of spinal position during the rowing stroke (i.e. at the catch and end of drive), and the orientation of the mounting blocks relative to the spine was measured. Construction lines were drawn on the MR scans through the middle of the high intensity signal of the castor oil markers and at the posterior margins of the high intensity signal from the intervertebral bodies from which relative rotations were measured (Figure 2) These construction lines were drawn five times by one observer and the average readings taken. Scans were taken with the rower pulling hard on the oar to simulate rowing conditions.

Data and statistical analysis

Kinematic data were recorded for three body segments: femur, pelvis and thorax. Data in the flexion/extension plane were analysed and the rowing stroke characterised in percentage points starting at the ‘catch’ position. This position was defined as the point of maximal femoral flexion. Femoral flexion, lumbo-sacral and thoraco-lumbar angular motion were compared for the five rowing conditions: warm, fatigued, bum-shove, taking the catch, leaning back. These were analysed using a two way ANOVA for each percentage point of the stroke. The statistical threshold was set at $p < 0.05$. Orthogonal contrasts were then employed to locate where any differences noted by the ANOVA lay.

Results

MRI Evaluation

The change in orientation in the sagittal plane of the underlying vertebrae from the orientation of the castor oil markers fixed to the electromagnetic device mounting blocks between the two spinal positions was defined as the error in measuring changes in spinal flexion/extension. The average error was $\pm 1.0^\circ$ (S.D. 1.0° , six subjects).

Femoral Flexion Angle

The femoral flexion angle deviated between rowing styles at different stages of the stroke. Significant changes ($p < 0.05$) occurred during the 35-50% stage (that is, the late drive through finish to recovery stage 1) and during the 56-75% stages which incorporates the second recovery stage. Fatigued subjects presented with significantly less extension of the femur at the 35-50% stages when compared to their warm strokes and the poor technique strokes notably the bum shove and heavy catch techniques. The fatigued curves then demonstrated a more marked flexion of the femur through out the second stage of the recovery when compared with the other stroke output data. The heavy catch and excessive leaning back techniques deviated from the warm technique during the second stage of recovery, both exhibiting less femoral flexion ($p < 0.05$).

Lumbo-Sacral Angle

Considerable variation was seen in the lumbo-sacral angle during each of the different rowing styles (Figure 3). Significant differences ($p < 0.05$) occurred during the 1-15% stage (that is the first part of the drive phase), and the 30-100% stage of the stroke which is the third stage of drive right through to the finish and recovery phases. The bum shoving technique demonstrated marked differences from the other techniques, particularly during the first stage of the drive phase ($p < 0.01$), with the delay in rotation of the pelvis on the femur. At the

finish, the bum shoving technique resulted in the pelvis being held in a more upright position compared to the other techniques ($p<0.05$). The fatigued recording demonstrated that the lumbo-sacral angle was greater than compared to the aberrant rowing techniques suggesting that as fatigue sets in, control of the rotation of the pelvis on the femur deteriorates. Simulation of the excessive leaning back technique leads to significantly greater extension of the lumbo-sacral region (which can be interpreted as a marked posterior pelvic tilt) particularly at the late stages of drive, the finish and early recovery phase ($p<0.01$).

Thoraco-Lumbar Angle

Analysis of the thoraco-lumbar motion revealed significant differences in movement during the very early stages of the drive (% points 7 to 17) and then again during the later stage of drive through to the finish and the first stage of the recovery process (Figure 4). In the early drive phase of stroke up to the drive phase 2, the bum shoving technique was significantly different from the other techniques ($p<0.01$) in that during this technique the spine was held in the neutral upright position. This is an aspect of the error of this method of rowing whereby the legs are extended first and then the torso and arms are drawn into the stroke.

One of the most important differences noted in the movement of the thoraco-lumbar spine during the later phase of drive, the finish and at the early stages of recovery were the significant differences ($p<0.05$) between “warm” recordings of rowing stroke and those when the subject became fatigued. Fatigued subjects has greater relative extension between the thoraco-lumbar and lumbo-sacral body segments during these phases. The fatigued recordings of stroke also were significantly different from the bum shoving technique, and the heavy catch technique ($p<0.05$). At this stage of the stroke, the excessive follow-through or leaning back too far technique error was also significantly different from the normal “warm” technique, the bum shove, and heavy catch technique ($p<0.05$).

Discussion

The technique and electromagnetic device presented here can be used to measure spinal motion of a rower on a rowing ergometer, with the potential for real time feedback for training purposes. Deviation of the rowing style from an 'ideal' technique can be easily identified and corrected using this device. There are two significant deficiencies of this setup: first, there is no evidence to suggest that the spinal motion and loading is the same on an ergometer as on a rowing boat. Further work should include developing the methods to allow measurements of technique whilst rowing on the water. Secondly, this paper has not addressed the loading on the spine due to the changes in the motion characteristics, and hence, the mechanics of injury to the lower spine. Further improvements in the technical aspects of this setup may be made by the use of a long-range transmitter which could increase the accuracy of the measurements. Also, we have presented rotation in one plane (two dimensions), yet the device allows measurement of rotations and translations in three dimensions. When rowing on an ergometer rowers do not deviate much from a sagittal rowing action, yet when on water, sweep rowing clearly involves large rotations out of the sagittal plane. For these to be quantified using this device, validation for the out-of-plane rotations must be included in the MRI study before the three-dimensional data can be presented.

Conclusions

This study has demonstrated that it is possible to accurately record the motion of the lumbo-sacral spine and the thoraco-lumbar spine using an electromagnetic motion tracking system and that the measurements obtained from such a system can provide useful and important information on the motion of the body segments during rowing. The ability of this system to detect deviations from "good" safe rowing technique appear promising and suggest that this

system has the potential to be developed further to provide a biofeedback tool to coaches and rowers.

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Figure Legends

- Figure 1.** Mounting block fixation points to determine the angle of the body segments. The rower is modelled as a three-link rigid body. The zero position for rotations is in the upright seated position.
- Figure 2.** Testing the validity of the system by sagittal MR scans of the spine and receiver mounting blocks under simulated ergometer rowing conditions in the two extreme positions of spinal position in an interventional magnetic resonance scanner. The mounting blocks are shown in the MR image by using castor oil tablets as markers. The relative rotation of the markers with the underlying vertebrae between the two positions is a measure of the error in measuring rotation of the spine. The rotations are measured using the construction lines shown.
- Figure 3.** Lumbo-sacral flexion (comparing different rowing styles, average data for all subjects for all strokes).
- Figure 4.** Thoraco-lumbar flexion (comparing different rowing styles, average data for all subjects for all strokes).

Figure 1

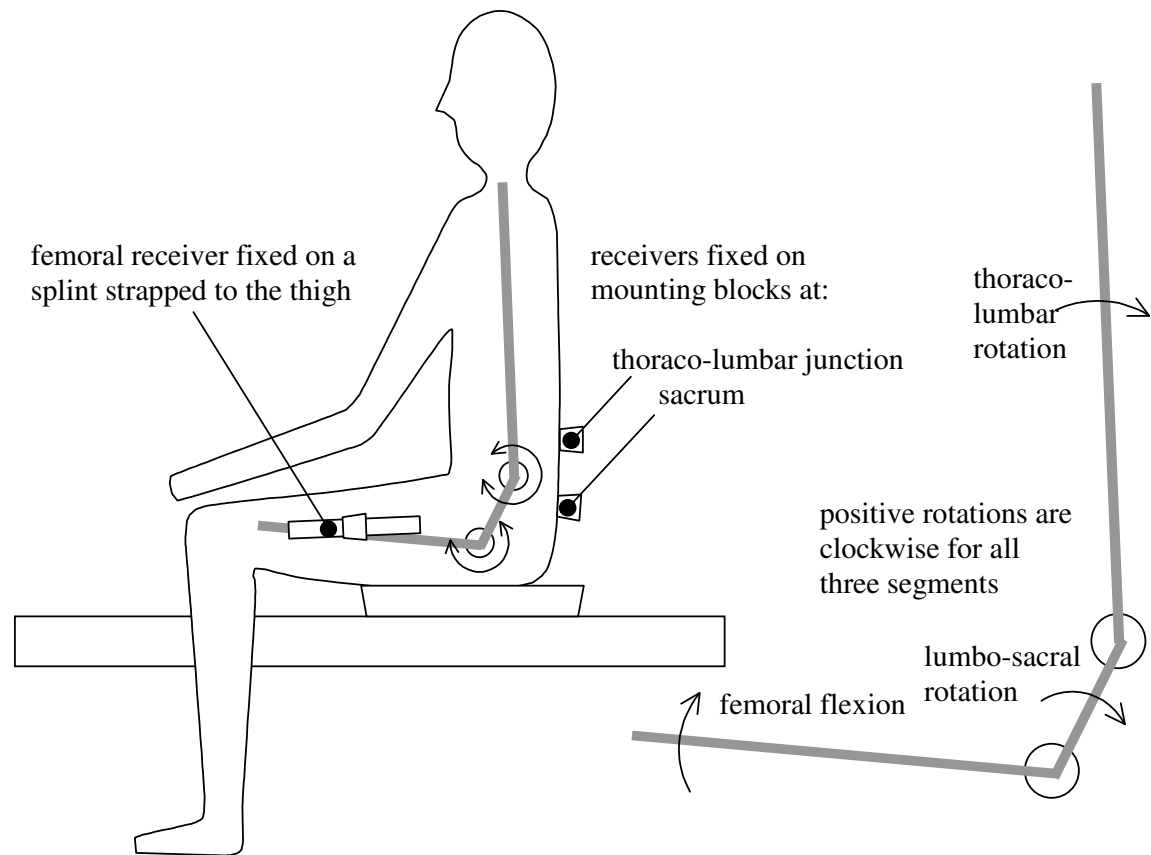


Figure 2 – original glossy provided.

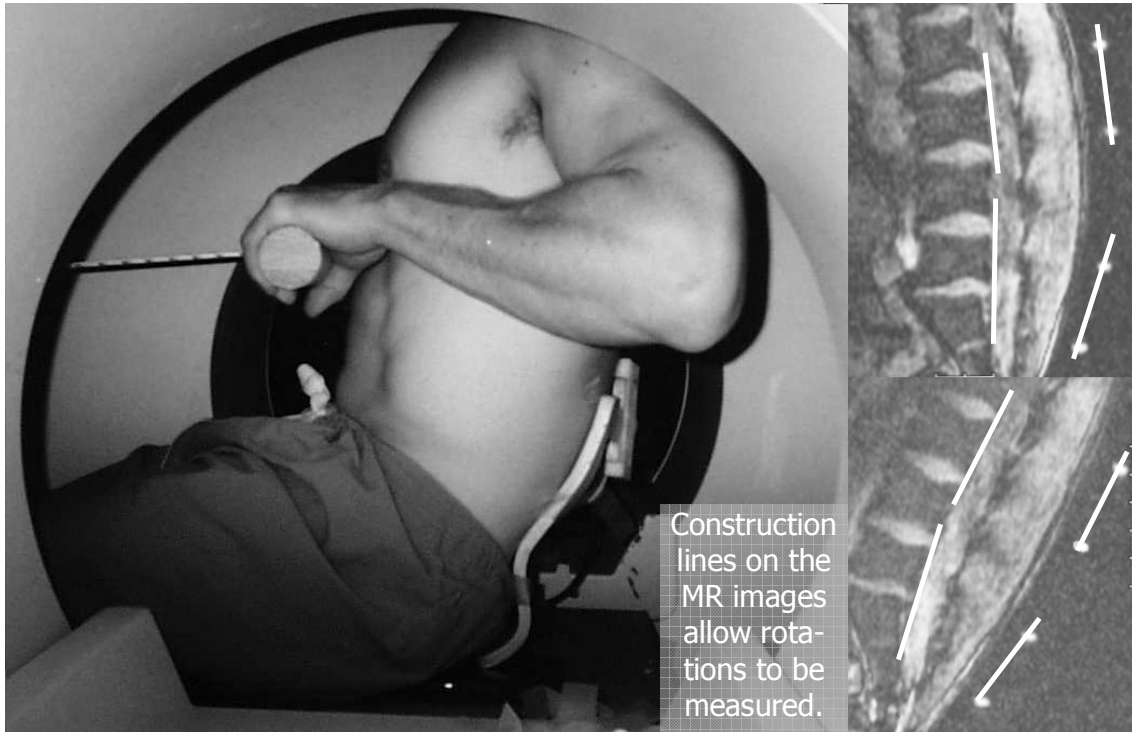


Figure 3

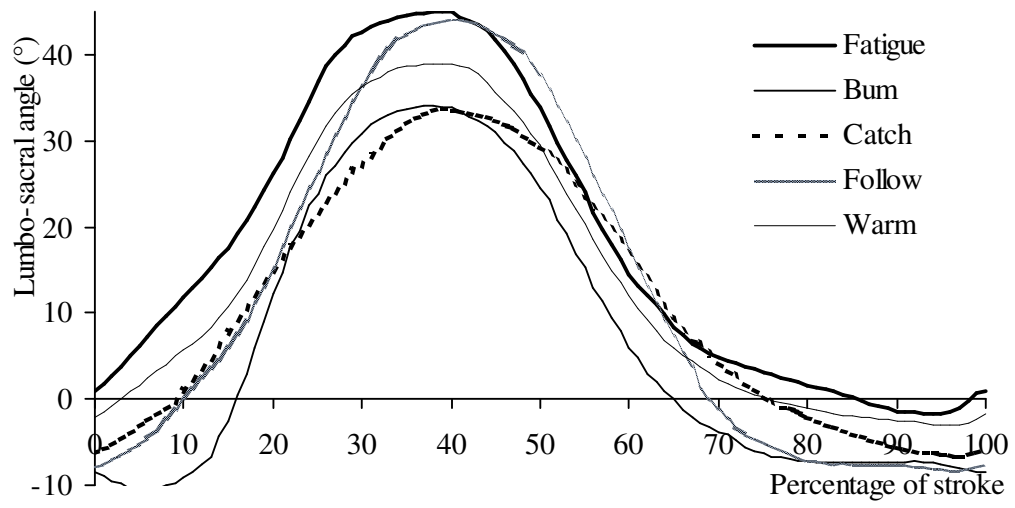


Figure 4

