Zeitschrift IJSM sm123 Satzbetrieb Ziegler + Müller
Verlag Thieme/Hentze Datum 09.01.2004

A. H. McGregor[1]
A. M. J. Bull[2]
R. Byng-Maddick[1]

A Comparison of Rowing Technique at Different Stroke Rates – a Description of Sequencing, Force Production and Kinematics

Abstract

Low back pain is the commonest musculoskeletal complaint in rowers. Research into the relationship between rowing technique, the forces generated during the rowing stroke and the kinematics of spinal motion are increasing, but to date none have investigated the impact of different rowing intensities on this relationship. A technique has been developed using an electromagnetic motion system and strain gauge instrumented load cell to measure spinal and pelvic motion and force generated at the handle during rowing on an exercise rowing ergometer. Using this technique ten collegiate male rowers (mean age 22.1 ± 2.8 years) from local rowing clubs were investigated. The test protocol consisted of rowing on an ergometer at three different stroke ratings; 17 – 20 strokes per minute; 24 – 28 strokes per minute; and 28 – 36 strokes per minute. Each rating was held for four minutes, with a five-minute rest between each rating. Marked changes in the force output curve and lumbopelvic kinematics were observed at the different rowing intensities. Although there was no change in the magnitude of peak torque generated during the different rating, there was a marked shift in when this occurred during the stroke. In terms of kinematic changes, these centred around changes in pelvic rotation at the catch and finish stages of the stroke with significantly less anterior rotation occurring at the catch position at higher rowing intensities. To conclude, this study suggests that rowing kinematics and force profiles do change at higher rowing intensities. These changes may be an important factor with respect to injury mechanisms, however, further work is required at an elite level.

Key words
Rowing kinematics · spinal kinematics · technique and intensity

Introduction

Rowing involves an interaction between physical strength, endurance, the skill and coordination of the athlete and the optimal design of the equipment. Although injury risk during rowing is low compared to other sports, particularly contact sports [7,17], there is increasing speculation that the rate of low back pain amongst rowers is increasing. A variety and range of injury mechanisms have been postulated including the nature of the sport itself and aspects of rowing technique, the weight-training regime and changes in rowing equipment [3,9,10,20,22].

Smith and Spinks [18] established that differences existed in both rowing capacity and skill at different competitive levels and that it was possible to depict such changes in skill using biomechanical variables. Over the past years the use of biomechanical variables to define technical skills has increased and expanded from traditional measures of stroke length, frequency,

Affiliation
[1] Musculoskeletal Surgery, Faculty of Medicine Imperial College London, Charing Cross Hospital Campus, London, United Kingdom
[2] Department of Bioengineering, Imperial College London, Bagrit Centre, Mechanical Engineering Building, South Kensington Campus, London, United Kingdom

Correspondence
Dr. A. H. McGregor · Musculoskeletal Surgery, Faculty of Medicine, Imperial College London, Charing Cross Hospital Campus · Fulham Palace Road · London W6 8RF · United Kingdom · Phone: + 44 20 83 83 88 31 · Fax: + 44 20 83 83 88 35 · E-mail: a.mcgregor@imperial.ac.uk

Accepted after revision: September 25, 2003

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Int J Sports Med 2004; 25: 1 – 6 © Georg Thieme Verlag · Stuttgart · New York · ISSN 0172-4622 · DOI: ■

consistency and efficiency [4,6,13] to detailed kinematics of body rotations [2,5,8].

Recent studies investigating the kinematics of rowing have illustrated clear patterns of lumbar and lumbo-pelvic motion with deviations occurring as a result of either fatigue or injury [2,8, 15,16]. However, these studies have focused on the elite club level rower as opposed to the average club level/recreational rower and have only considered low intensity ergometer rowing.

Rowers utilise different intensities of training on both land and water to achieve the optimal levels of fitness and technique for the race environment. Aspects of this training, more specifically low intensity long duration ergometer sessions, have been shown to change rowing techniques and it has been suggested that such changes may be important with respect to the development of low back pain [8]. To date little is known regarding the impact of such changes in intensity of training on kinematics parameters of rowing technique. It is hypothesised that different training intensities place different demands on the body and may lead to a compromise in technique that will place inappropriate demands on the musculoskeletal system. Such information is invaluable with respect to both performance enhancement and understanding potential injury mechanisms. This particular study seeks to determine the effects of different training intensities on the kinematics of the spine during ergometer land training in male club recreational level rowers.

Methods

Study population

The local research ethics committee approved this study and informed written consent was obtained from all subjects. Ten collegiate level male rowers were recruited into this study from Imperial College Medics, University College and the Royal Free Hospital Rowing Clubs. The mean age of subjects was 22.1 ± 2.8 years, with a mean height of 184.3 ± 6.0 cm and weight of 77.7 ± 9.2 kg. All athletes were sweep oarsmen with 4 rowing on bow side and 6 rowing on stroke side, and they had been rowing on average 6 ± 3 years. Each trained on average 15.8 ± 9.3 hours a week, with 50% of this training being on water, 25% on ergometers and the remainder either cross or weight training. Of the ten subjects eight had previously experienced some form of low back pain, but only two of these had had to take time off from training as a result of this pain. None of the subjects had low back pain at the time of testing.

Assessment of rowing kinematics

Lumbopelvic motion during the stroke was assessed using the Flock of Birds™ (Ascension Technology, Vermont, USA) electromagnetic measuring device as previously described [2]. This was further integrated with a load cell (Oarsum, NSW, Australia) positioned on the handle of the ergometer that permitted measurement of tensile force at the handle during the stroke [8]. This permitted investigation of lumbopelvic rhythm and force production during the stroke.

Protocol

All testing was performed on a Concept II model C rowing ergometer (Concept Inc, Vermont, USA). The receivers were positioned on the subjects as previously described [8]. Subjects were asked to perform a brief warm up. Once they were comfortable and the receivers were checked for any loosening or slippage, subjects were asked to perform three training pieces at three different rating; 17 – 20 strokes per minute (test A); 24 – 28 strokes per minute (test B); and 28 – 36 strokes per minute (test C). Each rating was held for four minutes, and subjects were encouraged to maintain as constant a stroke output as possible during this time. Subjects were given a five-minute rest between each rating.

Data analysis

The synchronised output from the Flock of Birds and load cell was run through an in-house custom programme. This programme focused on sagittal plane motion and characterised the stroke into percentage points with 0% representing the catch position of the stroke that was determined from the onset of tensile force production. Kinematic and tensile force data was averaged over each 4 minute time period and presented in terms of force, anterior-posterior femoral rotation (thigh flexion-extension), anterior-posterior sacral rotation (anterior/posterior pelvic tilt), and anterior-posterior lumbar rotation (back flexion and extension), Fig. **1**.

From these data the following were determined: peak force, power, work done through the stroke, and stroke length (determined by the travel of the handle). The point at which different phases of the stroke occurred were also examined including where peak force was achieved and when the drive phase ended. In addition, the following kinematics variables were examined: the angle of the femur, lumbosacral and thoraco-lumbar sensor at the catch and finish position, and the angle and position in stroke of maximum flexion and extension of the femoral, lumbosacral and thoraco-lumbar markers.

Statistical analysis

Statistical analysis of the data was performed using Analyse-It (Analyse-It Software Ltd., Leeds, UK) add-in for Excel (Microsoft Corp., Seattle, WA, U.S.A). Differences between the 3 rowing ratings for each of the variables were examined using ANOVA with Tukey's post hoc test being performed to locate where the differences lay.

Results

All subjects completed the test protocol. The average stroke rating for the first test (A) was 18.8 ± 0.5 strokes per minute, the second (B) 26.0 ± 0.8 strokes per minute and the third (C) 30.0 ± 1.0 strokes per minute.

Force output

There were marked changes in the shape and magnitude of the force curve at the three different ratings (Fig. **2**). Changes in peak force produced during the three different pieces were not, however, significant, although there was a trend towards a reduction in peak force at the higher stroke ratings, Table **1**. The point at

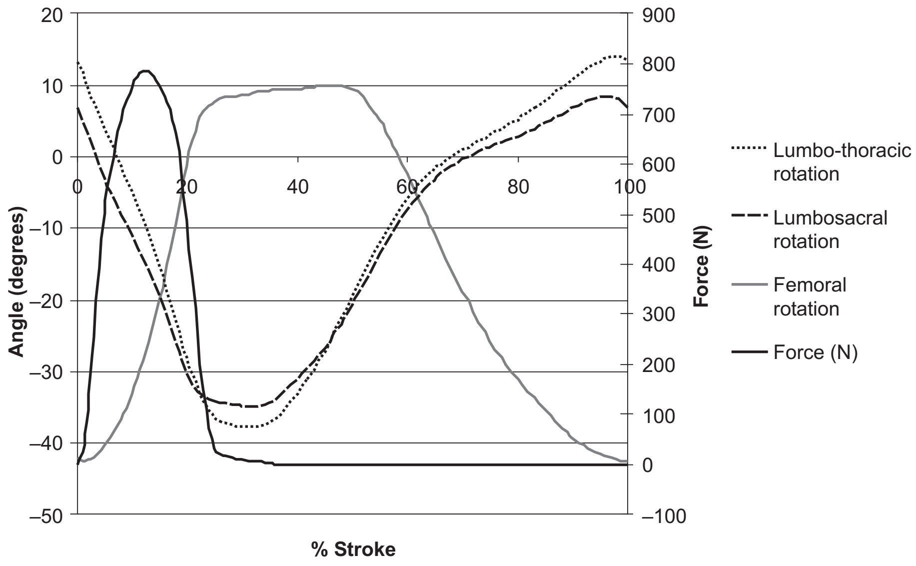

Fig. **1** An example of the averaged kinematic and tensile force data at the handle from one subject.

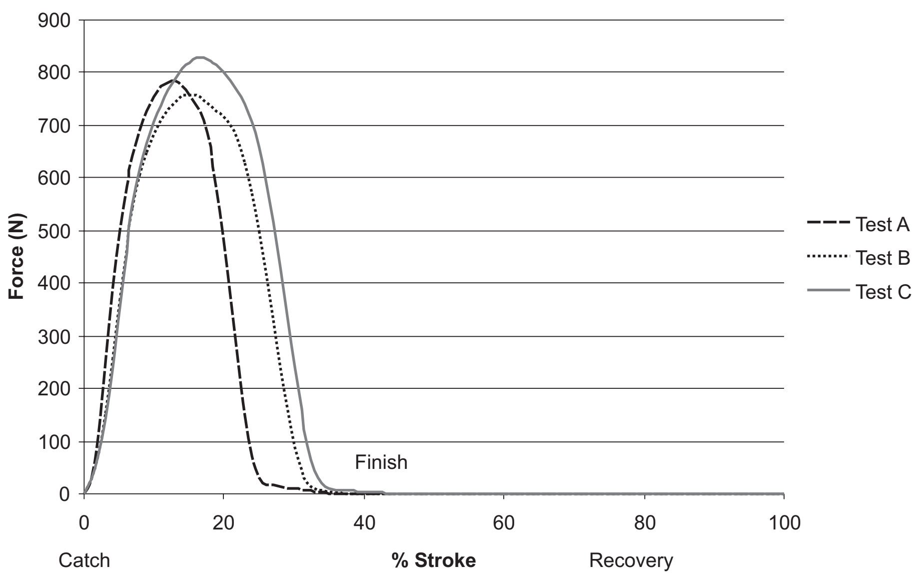

Fig. **2** An example of changes in tensile force profile curves in an individual during the rowing stroke at the three different stroke ratings. Test A = 17 – 20 strokes per minute. Test B = 24 – 28 strokes per minute. Test C = 28 – 36 strokes per minute.

Table **1** Changes in stroke profile at the different ratings (mean and standard deviation)

	Test A	*Test B*	*Test C*
Peak force (N)	832.7 ± 120.5	802.9 ± 92.2	789.9 ± 68.6
% Stroke when peak force occurs	13.3 ± 1.1	16.5 ± 1.4	18.8 ± 1.4
% Stroke when end of drive occurs	28.5 ± 2.9	35.8 ± 3.0	39.8 ± 2.8
Stroke length (cm)	149.9 ± 12.3	149.4 ± 10.5	147.3 ± 9.4
Power (W)	228.3 ± 32.9	299.5 ± 32.6	340.8 ± 28.9
Work done (Nm)	730.1 ± 108.6	690.2 ± 66.2	668.2 ± 57.9

Test A = 17 – 20 strokes per minute; Test B = 24 – 28 strokes per minute; Test C = 28 – 36 strokes per minute

which peak force occurred during the stroke was significantly later in the stroke at the higher stroke rating ($p < 0.001$). This was associated with the end of the drive occurring at a later stage in the stroke ($p < 0.001$). A separate analysis showed that the handle position at peak force was approximately the same over all the stroke ratings. Stroke length (as determined by the distance the handle moved) remained relatively consistent throughout the three different tests. The amount of work done throughout the stroke was reduced at the higher ratings, although this was not significant. Power, however, significantly increased at the higher stroke ratings, $p < 0.001$, with significant differences being noted at each rate change.

Femoral rotation

Interesting patterns of variability were seen in the kinematic parameters. Femoral rotation through the stroke altered due to the different ratings (Fig. **3**). The magnitude of maximal femoral flexion and the stage at which it occurred, just prior to the catch phase, did not alter significantly. However, there was a trend for femoral flexion to increase as the stroke rating increased (test A

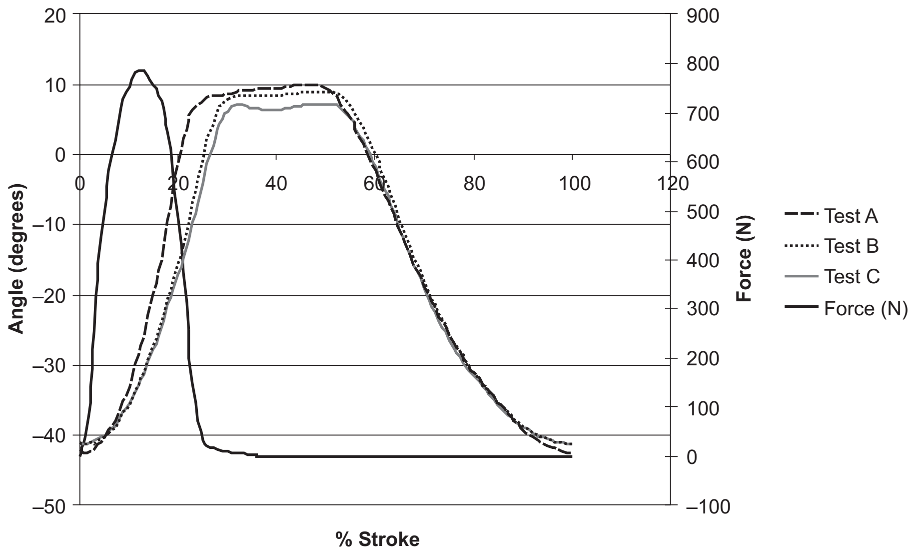

Fig. **3** An example of changes observed in femoral rotation in an individual uring the rowing stroke at the three different stroke ratings. Test A = 17 – 20 strokes per minute. Test B = 24 – 28 strokes per minute. Test C = 28 – 36 strokes per minute.

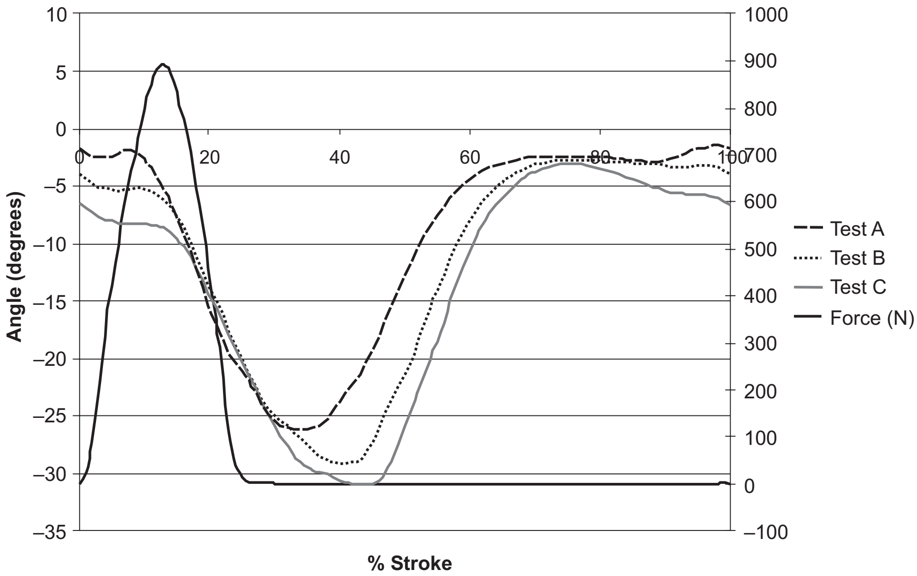

Fig. **4** An example of changes observed in lumbopelvic rotation in an individual during the rowing stroke at the three different stroke ratings. Test A = 17 – 20 strokes per minute. Test B = 24 – 28 strokes per minute. Test C = 28 – 36 strokes per minute.

44.1° ± 3.6; test B 46.0° ± 5.3; test C 48.9° ± 6.0). Femoral extension also changed non-significantly through the 3 test protocols. At the higher rating it was observed that less leg extension occurred (test A 2.6° ± 5.4; test B 0.2° ± 5.6; test C – 1.7° ± 5.6) with the legs being driven down earlier in the stroke at the higher ratings (test A 46.1 % ± 11.9; test B 39.7 % ± 9.4; test C 38.1 % ± 3.5).

Lumbopelvic rotation

Lumbopelvic rotation changed markedly with increased stroke rating (Fig. **4**). Anterior lumbopelvic rotation (anterior pelvic tilt) at the catch reduced significantly at the higher stroke ratings ($p < 0.001$). The most significant changes were observed between test A and C (test A 0.6° ± 4.3; test B – 2.9° ± 5.3; test C – 6.3° ± 6.6). No changes were observed in the timing of this maximal anterior tilt.

Posterior lumbopelvic rotation tended to occur near the finish position. The stage at which this occurred became significantly later in the stroke as the rating increased ($p < 0.001$) (test A 34.4 % ± 3.4; test B 40.7 % ± 2.5; test C 42.1 % ± 3.4). Although no significant change was observed in the degree of posterior rotation, a tendency for posterior rotation to increase at higher ratings was observed (test A – 44.5° ± 13.3; test B – 47.0° ± 2.5; test C – 47.8° ± 11.7).

Lumbothoracic rotation

The changes in lumbopelvic motion were reflected in changes in lumbothoracic rotation (Fig. **5**). As anterior lumbopelvic rotation reduced at the catch, so did lumbothoracic flexion, although this was not significant (test A 17.7° ± 6.1; test B 14.8° ± 4.9; test C 12.7° ± 5.7). In terms of lumbothoracic extension at the finish of the stroke, the angle of extension did not alter significantly; however, the point at which this occurred during the stroke became significantly later ($p < 0.001$) as the ratings increased (test A 34.2 % ± 3.3; test B 40.9 % ± 3.3; test C 42.4 % ± 4.0).

Event timings

Little consistency was observed in the timing of the maximum body rotations leading to the catch position. Maximum anterior lumbopelvic rotation, maximum thoracolumbar rotation and maximum forward position of the hands all occurred at approximately the same time as the catch position was achieved. Max-

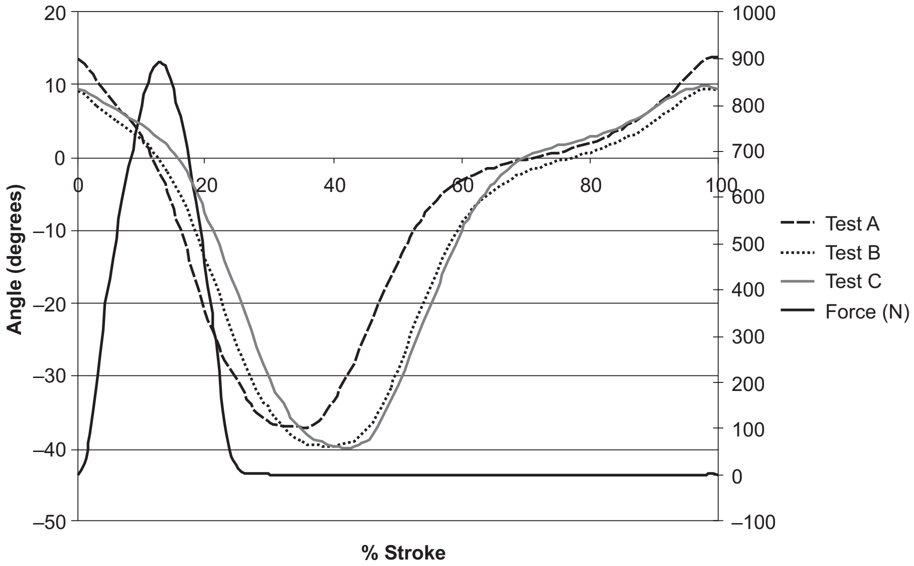

Fig. **5** An example of changes in thoracolumbar rotation in an individual during the rowing stroke at the three different stroke ratings. Test A = 17 – 20 strokes per minute. Test B = 24 – 28 strokes per minute. Test C = 28 – 36 strokes per minute.

imal femoral flexion occurred just after this. In two subjects maximal flexion occurred later after the load on the handle had been picked up. Following the pick-up of load on the handle, it was noted that for most subjects the femur started extending after the lumbopelvic and thoraco-lumbar spine had initiated extension and after the handle had started moving away. Changes in these sequences were noted at the higher stroke ratings. At the finish of the stroke, again consistency in the timing of maximum posterior body rotations appeared poor. For most subjects the initiation of the finish phase was characterised by rotation of the femur into extension. However, the sequencing of posterior lumbopelvic tilt, thoracolumbar extension and movement of the hands away from the trunk varied considerably between subjects and between ratings. Similar variability was observed during the recovery.

Discussion

Rowing is a complex movement involving sequential extension and flexion of the legs, trunk and arms [18]. An understanding of the mechanics of rowing, and the training procedure is thought to be essential for caring for injured rowers and may have important implications for understanding injury mechanisms. Since Stallard [20] postulated that the majority of low back pain injuries in rowers were of mechanical origin and related to rowing technique, it would thus appear important to investigate the kinematics of rowing. The assessment of on-water kinematics has proven difficult and thus frequently such parameters are assessed on a stationary rowing ergometer, which has been shown to simulate on-water rowing [12].

Several groups have initiated research in this area with Hawkins [5] developing an electrogoniometric method for assessing the kinematics of rowing, and Shian and Tsai [18] a camera-based system. Both, however, considered the trunk as one whole and did not differentiate lumbopelvic rhythm. This may be of importance since Timm [21] postulated that up to 54% of reported lumbar spine injuries in a senior national rowing team resulted from a sacroiliac dysfunction. More recent studies investigating the kinematics of rowing have illustrated clear patterns of lumbar and lumbo-pelvic motion with deviations occurring as a result of either fatigue or injury [2,8,15]. Of particular concern was the increased used of the lumbar spine during rowing as the rower tired [8]. McGregor et al. [15] noted marked alterations in lumbo-pelvic rhythm as a result of low back pain in elite rowers.

However, research into recreational or club level rowers is scarce. Smith and Spinks [18] have previously noted that differences in rowing capacity and skill occur at different performance levels, noting that the ability to stay in time with other crew members and to obtain maximum propulsion is largely dependent upon the accurate and continuous replication of effective stroke patterns. Similarly Shiang and Tsai [18] noted a reduced force time curve slope for general level rowers as compared with elite. In addition, very little is known about the effect of changes in stroke rate on the various movements the oarsman has to perform during the stroke cycle [14]. This study sought to investigate these issues by studying the rowing kinematics in collegiate rowers and the effect of rowing intensity on their technique.

Peak force production in this group of athletes was in line with previously published data [8,19]. However, changes in this force curve profile were observed at different rowing intensities, specifically a reduction in force curve profile was observed, and peak force was noted to occur later during the stroke with a subsequent delay at the end of the drive phase; this concurs with the findings of Martin and Bernfield [14]. Technically coaches strive for athletes to maintain the same curve shape during different rowing intensities although commonly it is observed in elite athletes that there is a shift in the force curve to the left, that is, there is a delay in the rate at which force is generated and that this high level of force is sustained for longer. This, however, was not observed in our recreational rowers. This may be due to mistiming of the catch phase of the stroke as the rowing intensity increased, which is a common error in novice and recreational rowers, and is in accordance with the poor sequencing also observed in this study. Hartmann et al. [4] previously noted decreases in peak force during a six minute rowing piece that he at-

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tributed to different stroke rating during the stroke, and suggested that a short stroke length was associated with a higher peak force power. Stroke length in this study, however, was not observed to alter significantly.

More interesting patterns were observed when the kinematics of the spine were considered, the most marked changes occurring in the lumbar spine and pelvis. With increasing stroke rate rowers were noted to achieve less anterior rotation of the pelvis at the catch position, suggesting that they were not getting full "rock over", a common technical finding. Rotation of the lumbar spine was also seen to decrease suggesting that rowers were using thoracic flexion and shoulder protraction to maintain stroke length. The full significance of such changes is unclear at present but may be important with respect to injury mechanisms. A trend towards greater posterior pelvic tilt at the finish was also observed. This suggests that rowers were "slumping" at the finish and this may have relevance in terms of its effects on boat speed, since maximum boat speed occurs during recovery [14]. It may also be important with respect to injury mechanisms or, as noted by Holt et al. [8], be indicative of a weak trunk stabilising mechanism.

Changes in leg kinematics were also observed with many rowers being unable to maintain or even achieve leg extension at the finish of the stroke. This may be associated with numerous factors including lack of stability at the trunk and pelvis [11] or inflexibility of the hamstring muscle group. In conjunction with the loss of pelvic rotation at the catch, increased femoral rotation was observed at the catch position leading to a faster leg drive phase. The injury and performance implications of this are at present unknown. Lamb [12] noted that the lower leg was responsible for initiating the drive phase of rowing and that the trunk should equal this half way through the stroke. The current data would suggest that the trunk is being "left behind" at the higher ratings such as occurs during the "bum shoving" technique previously noted [2].

Lamb [12] noted that the literature was inconclusive concerning an accepted sequence of body action for initiating the drive phase in the rowing stroke, and little data exists in terms of sequencing during the whole stroke. This is surprising since Baudouin and Hawkins [1] suggested that coordination and synchrony between rowers in a multiple rowing shell would impact on the overall system velocity, a theory also put forward by Wing and Woodburn [23]. This study has suggested that consistency in body action sequencing is poor, and this therefore may be an important area for rowing coaches and therapists to address. However, further work with more experienced rowers is required.

Conclusions

Consistency in rowing stroke kinematics at a collegiate level is poor. Marked changes in kinematics occur as the stroke rate is increased; however, the full implications of this with respect to injury remain speculative.

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