©Journal of Sports Science and Medicine (2007) **6**, 29-35
http://www.jssm.org

Research article

Longitudinal changes in the spinal kinematics of oarswomen during step testing

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Abstract
Earlier studies have investigated the biomechanics of rowing during step testing with a focus on lumbo-pelvic kinematics and force output and noted that these parameters change with work intensity. The aim of this study was to investigate how the biomechanics of the rowing stroke changes over time as a result of coaching and training and to see if these change were related to a change in physiological performance. An electromagnetic motion measuring device in conjunction with a load cell was used to determine the ergometer rowing kinematics of 7 elite international oarswomen during routine step tests over a two year period. Force output was observed to improve over the two year time period, with peak force significantly rising by 40-80 N. This was associated with significant increases in stroke length of between 15 and 19 cm. Both of these are indicative of improvement in performance. Kinematic variables were also observed to change, with greater pelvic rotation and associated lumbar spine motion at the later time point. The findings of this study demonstrate that rowing technique changes with time, and suggest that kinematics measures of rowing technique may be important tools to monitor athletes.

Key words: Stroke length, performance, lumbo-pelvic motion force output.

Introduction

Competitive rowing is primarily an endurance activity, with almost 80% of the rower's metabolic contribution to a rowing race coming from the aerobic energy pathway (Pripstein et al., 1999). Maximal oxygen uptake and maximal aerobic power are significantly correlated to 2000m performance (Soper and Hume, 2004), with many studies suggesting that changes in physiological profiles are associated with increased winning potential (Messonnier et al., 1997; Fiskerstrand and Sieler, 2004). Consequently physiological factors, particularly cardiorespiratory and metabolic changes, are frequently used to assess aerobic performance and changes in performance with time and aging (Hagerman et al., 1996).

There are a number of physiological tests that assess a rower's endurance capacity and work output (Ingham et al 2002, Secher et al 1983). An incremental "step test" measure the relationship between the work output of the rower and the physiological response to that work. This may be achieved through measuring the rower's oxygen uptake or heart rate response and lactate accumulation (Beneke 1995, Forsyth and Reilly 2004). When the physiological parameters are plotted against the rower's work output, a curve is formed that allows individualised training intensities to be set, as well as monitoring the effectiveness of the rower's training (Beneke 1995).

Recently this form of incremental testing on rowing ergometers at different work intensities has been utilised to quantify biomechanical parameters of technique in terms of musculoskeletal kinematics and force production (McGregor et al., 2005). Although such tests are not of maximal race performance, they do permit a range of performance levels to be assessed in a controlled manner. Studies focusing on the biomechanics of boat performance have suggested that performance cannot be predicted from propulsive power, synchrony of propulsive force and drag and indicated that other biomechanical parameters were involved (Baudouin and Hawkins 2002; 2004). Although the kinematics of rowing technique are thought to contribute to rowing performance (Soper and Hume, 2004), it is still not clear what aspects of technique are important in terms of predicting 'on water' performance, although stroke length has been highlighted by coaches to be of importance. Similarly, it is not known how technique changes in response to training load and coaching and whether such changes are of importance with respect to performance, although intuitively it is believed that such measures enhance technique. Therefore, the aim of the present study was to examine whether biomechanical measures of the kinematics of rowing technique assessed during a routine step test change over time in a group of international female rowers as a result of training and additional trunk strengthening work.

Methods

Study Population

This study received local ethical approval, and all participants provided written informed consent. In the initial phase of this study, 12 elite oarswomen from the Great Britain National Team were recruited. By the 2nd phase of the study performed 2 years later but at the same point in the training year only 7 of the 12 remained in the National Team; this study focuses on these 7. During this 2 year interval all were full time athletes following the same basic training programme provided by their head coach which included an additional twice weekly trunk strengthening programme. Due to the competitive level and size of the training squad it was not possible to have a control group. On completion of the study, their mean age was 25.6 years ± 4.3 [sd], mean height 1.83 m ± 0.06, and mean weight 75.1 kg ± 4.6.

Assessment of rowing kinematics

An electromagnetic system, the Flock of Birds™ (Ascension Technology, Vermont, USA) was used to assess the kinematics of the lumbopelvic region. This system quantifies the motion of sensors (which can be aligned to body

Received: 21 June 2006 / Accepted: 02 December 2006 / Published (online): 01 March 2007

segments) in an electromagnetic field in terms of rotation about and translations along an electromagnetic transmitter axis, and has been shown to have acceptable accuracy (Bull et al., 1998). The receivers of the system were attached to the skin at the thoracolumbar junction (T12) (thereby measuring anterior-posterior lumbar segment rotation that is lumbar flexion and extension), the lumbosacral junction (S1) (measuring anterior-posterior sacral rotation or pelvic tilt), and 10 cm proximal to the lateral epicondyle of the right femur (measuring anterior-posterior femoral rotation or thigh flexion-extension) as described and validated by Bull and McGregor (2000) and Bull et al., (2004). The electromagnetic transmitter was aligned with the plane of movement of the ergometer, so that sensor movement on the landmarks was recorded as a rotation in the sagittal plane (flexion/extension), and out-of-plane rotations. This system 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 (Holt et al., 2003). An additional sensor was placed on the handle to determine the position of the handle in space and to permit the calculation of stroke length, work performed, and power.

Incremental "step" test

Each athlete performed an incremental exercise test comprising 5 steps on a Concept II model C rowing ergometer (Concept Inc, Vermont, USA). This step test is defined as follows: each rower's initial power output was determined from her current personal best 2000 m ergometer time. Five sub-maximal steps each of four minutes in duration and separated by a one minute rest are defined so that the power output of each of the five submaximal steps increased by 25W and scaled for the power to be approximately 80% of their 2000 m level at the fifth step. Athletes are asked to maintain the following stroke rates for the five submaximal steps; 18, 20, 22, 24, 26 strokes per minute.

Protocol

The receivers of the electromagnetic motion system were positioned on the subjects and a brief warm-up was performed on the ergometer for 10 minutes using a low rating of between 18-20 strokes per minutes. The receivers were checked to ensure that the sensor remained appropriately attached to the subject, and the incremental 'step' test was performed. Tests were performed on the same group of athletes twice with a two year interval between testing (time A and time B) with testing performed at the same point in the training season, using the same protocol and same equipment.

Data analysis

The synchronised output from the Flock of Birds and load cell was run through an in-house custom software program. This program 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, and 100% representing the return to this catch position. This data normalisation allows kinematic data to be compared within and between individuals. This technique is common in kinematic analysis of repetitive activities (Shapiro et al., 1981). The following derived data were recorded for each stroke: peak force, work done through the stroke (ie area under curve), and power (work done divided by time of the stroke). Stroke length which was defined as the maximum horizontal travel of the handle was also noted (Holt et al., 2003). The data were averaged over each of the steps, with the initial and final strokes eliminated from the analysis, 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).

The point at which different phases of the stroke occurred were examined, including where peak force was achieved and when the drive phase ended. For the kinematic analysis the catch was defined as the onset of tensile force production and the finish as the point at which there was no force application at the handle. Using these definitions, the angle of the femur, lumbar spine and pelvis were determined in both catch and finish position. Further, the angle and position in the stroke of maximum flexion and extension of all three markers was determined. Finally, the ratio of lumbar spine rotation to sacral rotation was determined at the catch and finish positions.

Statistical analysis

Statistical analysis of the data was performed using Analyse-It (Analyse-It Software Ltd., Leeds, U.K) add-in for Excel (Microsoft Corp., Seattle, Wa, U.S.A). Differences between the 5 rowing incremental steps for each of the variables during each of the step tests at each time point were examined using repeated measures ANOVA. Paired Student T-tests and Bonferroni adjustments were utilized to explore these differences. The statistical threshold was set at $p < 0.05$.

Results

Data were collected successfully on all seven subjects at each time point.

Force output

For both time A and B, peak force was observed to increase significantly over the 5 steps ($p < 0.001$), showing incremental rises with each step. The average stroke rating for each incremental step however were slightly lower at time B. In addition, a significant rise in peak force occurred at time B ranging from an increase of 40 to 80 N for the five steps ($p < 0.01$, Table 1), with steps 2and 5 demonstrating significant improvements in force output between time points A and B ($p < 0.05$). An example of the changes can be seen for one athlete in Figure 1. The position during the stroke when peak force occurred did not alter between time A and time B, although within incremental tests it was observed to occur later in the stroke with increased stroke ratings with each incremental step. The changes between steps and time points were observed when power and work done were considered (Table 1), with significant rises in power and work done with incremental step ($p < 0.001$) and time point ($p < 0.0001$), these rises were observed for all incremental

Table 1. Changes in the force curve profile and stroke profile during the incremental test (n=7). Data are means (±SD).

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B
Stroke rate	17.1 (.7)	16.5 (.8)	18.1 (.5)	17.5 (.6)	20.1 (1.2)	18.9 (1.0)	21.4 (1.3)	20.8 (1.3)	23.4 (1.4)	23.2 (1.2)
Peak force (N)	621 (74)	684 (96)	666 (57)	739 (80)	691 (85)	767 (77)	723 (87)	783 (73)	746 (77)	792 (67)
% Stroke when PF occurs	13.3 (1.9)	12.9 (2.0)	13.4 (2.1)	13.4 (1.8)	14.3 (1.9)	14.1 (1.7)	15.3 (2.5)	15.4 (1.7)	16.3 (2.4)	16.9 (1.7)
% Stroke when ED occurs	46.4 (7.1)	30.4 (2.3)	40.6 (2.6)	30.9 (2.1)	42.7 (3.2)	31.7 (1.8)	46.4 (3.2)	33.9 (2.4)	46.4 (7.1)	36.3 (2.1)
Stroke length (cm)	138 (.6)	154 (.5)	140 (.6)	155 (.5)	137 (.9)	156 (.4)	138 (.9)	156 (.4)	141 (.7)	156 (.5)
Power (work done/ stroke)	150 (11)	175 (14)	170 (8)	198 (15)	193 (18)	223 (15)	216 (11)	251 (15)	242 (10)	279 (13)
Work done (J)	530 (49)	640 (66)	568 (34)	680 (53)	586 (66)	711 (56)	609 (61)	725 (55)	621 (54)	725 (53)

Abbreviations: PF = peak force, ED = end of drive.

steps ($p < 0.05$).

A non-consistent stroke length was observed at time A. This appeared more stable by time B (Figure 2) and showed a significant increase in overall stroke length ($p < 0.0001$) which ranged from 14.9 -18.9 cm in terms of group average across incremental steps, these differences were significant for each incremental step ($p<0.05$). The point at which the end of the drive phase occurred was earlier in the stroke at time B suggesting a more efficient stroke profile and a faster more co-ordinated drive phase, allowing more time for the recovery phase. This is supported by the fact that the stroke length and force has increased, leading to a rise in power for the same physiological work load. Further, Table 1 suggests that if anything stroke rates for the later step tests were slightly lower again enhancing the suggestion of a more efficient stroke.

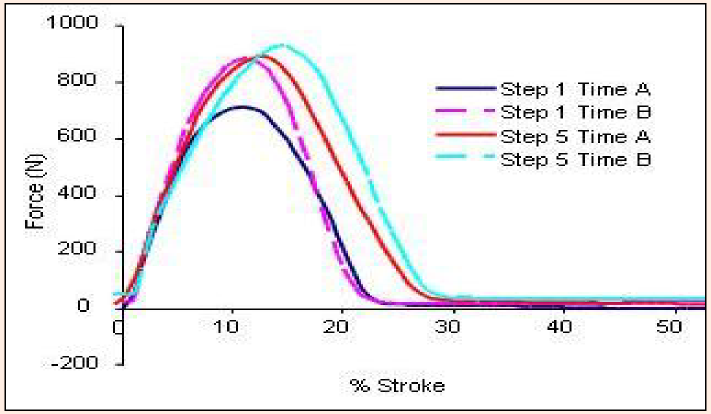

Figure 1. An example of the changes in force curve over two of the different steps at each time point in one athlete.

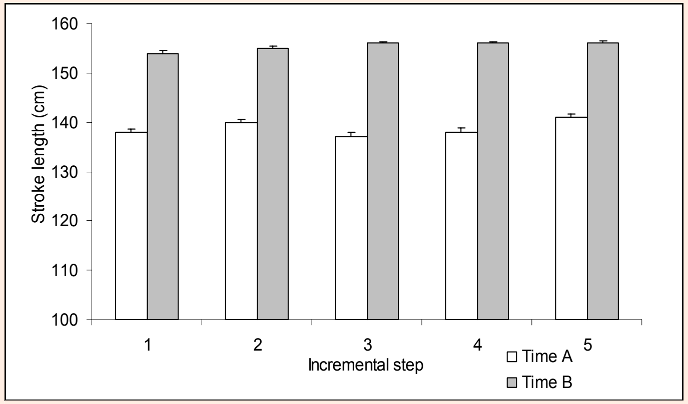

Figure 2. Changes in stroke length during the incremental step test (n = 7, all measures in cm).

Femoral rotation (thigh flexion/extension)

Minor changes were seen in the magnitude of femoral rotation at the catch position (thigh flexion) during the step test at both times A and B (Table 2). However, there was a clear reduction in the magnitude of thigh flexion at time B ($p < 0.001$), at all incremental steps apart from the 3rd. This may be associated with the kinematic changes noted below. A similar reduction was observed in maximal thigh flexion occurring during the stroke (Table 2). The point during the stroke at which occurred showed no clear trend.

Femoral rotation (thigh extension) at the finish position fluctuated more at time A. For both times A and B thigh extension was lower at the later incremental steps (Table 2). Overall, more thigh extension was observed at the finish at time B ($p < 0.05$) but

Table 2. Changes in thigh rotation during the incremental test (n=7), NB movements into flexion negative, movements into extension positive. Data are means (±SD).

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B
Thigh flexion at the catch (°)	-40.5 (4.8)	-36.2 (2.6)	-40.5 (4.6)	-36.9 (2.9)	-39.9 (3.1)	-36.8 (2.9)	-41.0 (4.3)	-36.9 (2.9)	-40.9 (8.0)	-37.6 (3.1)
Maximal thigh flexion (°)	-40.2 (5.3)	-36.8 (2.2)	-40.9 (5.4)	-37.6 (2.4)	-39.7 (2.5)	-37.5 (2.4)	-41.3 (4.1)	-37.6 (2.3)	-40.3 (8.5)	-38.3 (2.6)
% stroke where maxTF occurs	96.9 (2.7)	97.4 (2.0)	96.9 (2.8)	97.1 (2.4)	97.4 (2.3)	96.6 (2.6)	96.9 (2.0)	96.7 (3.1)	96.6 (2.0)	96.6 (3.3)
Thigh extension at the finish (°)	3.0 (5.5)	7.2 (4.9)	6.5 (2.6)	6.8 (5.1)	5.7 (1.9)	6.5 (5.3)	3.9 (1.3)	6.3 (5.2)	2.2 (2.2)	5.7 (5.6)
Maximal thigh extension (°)	7.7 (2.5)	8.9 (3.8)	7.8 (3.1)	8.7 (3.9)	7.8 (2.5)	8.7 (4.4)	7.4 (3.0)	8.4 (4.6)	6.2 (3.8)	8.0 (4.9)
% stroke where maxTE occurs	34.3 (6.3)	32.1 (11.4)	30.4 (6.1)	35.4 (11.2	31.4 (5.8)	29.4 (9.5)	29.4 (3.2)	30.3 (9.1)	30.6 (3.4)	32.1 (8.1)

Abbreviations: maxTF = maximal thigh flexion, maxTE = maximal thigh extension.

only in the 4th and 5th incremental steps. Similarly, greater maximal thigh extension over the whole stroke was observed at time B but this did not reach significance, and no differences were observed with respect to the point at which this occurred in the rowing stroke.

Sacral rotation (pelvic rotation)

Sacral rotation (anterior rotation of the pelvis) at the catch remained consistent throughout each incremental step, however, by time B, the athletes were able to achieve significantly greater anterior rotation ($p < 0.001$) during steps 1-4. This was also reflected in the magnitude of maximal anterior rotation that they could achieve ($p < 0.001$), and there was a non-significant trend ($p = 0.09$) for the athletes to achieve this earlier in the stroke (Table 3).

At the finish position, the data from time A revealed variability in the degree of posterior rotation achieved at each of the different incremental steps (Table 3). In contrast, time B revealed greater consistency and a greater magnitude of posterior rotation at the finish position, ($p < 0.01$, Table 3), this only reached significant at step 1. This increased magnitude was also observed with respect to maximum posterior rotation over the whole stroke, and this maximal rotation occurred significantly earlier in the stroke ($p < 0.001$) at time B.

Lumbar rotation (lumbar spine flexion/extension)

The above changes in pelvic rotation were complemented by changes in lumbar rotation (lumbar spine flexion/extension). At the catch, values of lumbar flexion remained approximately the same at each incremental step (Table 4). However, they were observed to increase as greater forward lumbar rotation or lumbar flexion was achieved ($p < 0.001$) at time B during incremental steps 1-4. This can be attributed to the improved pelvic position noted above. The magnitude of this increase in flexion was less when maximum forward lumbar rotation (flexion) during the stroke was considered, although the increase was still statistically significant ($p < 0.001$). This maximal forward lumbar rotation occurred later in the stroke as incremental step increased ($p < 0.001$), but tended to occur earlier in the stroke at time B compared to time A ($p < 0.0001$).

Lumbo-pelvic ratio

Lumbo-pelvic ratio was determined at the catch and finish and represents the ratio of the lumbar rotation to the sacral rotation, where a value of 1 demonstrates equal contribution of each body segment to the forward motion of the trunk as a whole. At time A, the lumbo-pelvic ratio was observed to increase with incremental step indicating a predominance of lumbar motion, however, by time B not only had this ratio improved (become close to 1), it demonstrated greater consistency with minimal

Table 3. Changes in pelvic rotation during the incremental test (n=7). Data are means (±SD).

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B
Posterior rotation at the finish (°)	-9.9 (7.2)	-20.6 (8.3)	-19.4 (3.5)	-21.7 (8.9)	-20.2 (5.6)	-23.0 (9.0)	-16.8 (5.2)	-23.4 (9.3	-17.3 (3.3	-25.3 (9.0)
Maximum posterior rotation (°)	-23.7 (6.9)	-20.8 (8.2)	-25.5 (7.0)	-22.0 (8.8)	-26.7 (7.4)	-23.1 (9.0)	-27.0 (7.4)	-23.6 (9.3)	-28.0 (7.7)	-25.5 (9.0)
% stroke where maxPR occurs	32.7 (3.4)	30.1 (3.1)	33.3 (3.1)	30.9 (2.4)	34.6 (3.4)	31.4 (2.7)	35.7 (4.4)	32.3 (2.8)	36.9 (4.2)	33.9 (2.4)
Anterior rotation at the catch (°)	12.6 (5.5)	19.0 (2.6)	12.7 (6.1)	18.7 (2.4)	12.1 (6.2)	19.2 (2.6)	12.4 (5.7)	18.9 (2.9)	12.5 (5.8)	17.4 (3.5)
Maximum anterior rotation (°)	15.5 (5.4)	22.7 (2.9)	15.1 (5.9)	22.0 (2.8)	14.1 (5.9)	21.6 (2.8)	14.5 (5.7)	21.1 (2.4)	14.4 (5.9)	19.0 (3.4)
% stroke where maxAR occurs	80.9 (10.2)	74.3 (10.1)	81.1 (9.4)	78.1 (12.1)	85.6 (9.2)	81.6 (12.5)	87.0 (8.8)	82.1 (11.6)	88.6 (8.2)	83.9 (10.6)

NB anterior rotation of the pelvis denoted by positive angles, posterior by negative. Abbreviations: maxPR = maximal posterior rotation, maxTE = maximal anterior rotation.

Table 4. Changes in lumbar rotation during the incremental test (n=7). Data are means (±SD).

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B	Time A	Time B
Flexion at the catch (°)	24.9 (5.3)	38.8 (3.9)	25.2 (6.1)	39.0 (3.9	24.6 (6.2)	39.0 (4.4)	24.9 (5.6)	38.6 (4.4)	25.6 (5.9)	37.0 (4.8)
Maximum flexion in stroke (°)	26.0 (5.2)	39.4 (3.7)	26.2 (6.0)	39.6 (3.7	25.6 (6.0)	39.6 (4.2)	25.9 (5.5)	39.0 (4.3)	26.4 (6.0)	37.4 (4.9)
% stroke where maxFlex occurs	95.7 (3.5	93.4 (3.7)	96.7 (2.3)	93.9 (2.8	96.9 (2.5)	94.1 (3.0)	97.1 (2.0)	94.4 (2.8)	97.3 (2.1)	96.6 (2.4)
Extension at the finish (°)	-9.9 (12.2	22.4 (5.9)	-24.0 (4.4)	23.4 (5.9	-24.5 (5.9)	25.4 (6.3)	-19.5 (5.5)	26.3 (6.5)	-20.8 (3.7)	28.9 (6.1)
Maximum extension in stroke (°)	-30.6 (3.8)	-22.6 (6.0)	-32.5 (3.9)	-23.7 (6.0)	-33.7 (4.8)	-25.5 (6.3)	-34.4 (5.1)	-36.5 (6.5)	-35.6 (6.5)	-29.2 (6.3)
% stroke where maxExt occurs	33.3 (2.6)	30.1 (2.1)	34.1 (2.6)	30.9 (2.0)	35.4 (3.0)	31.7 (1.3)	36.1 (3.5)	33.3 (1.7)	36.3 (3.8)	35.0 (1.8)

NB lumbar flexion is denoted by positive angles, extension by negative. Abbreviations: maxFlex = maximum flexion, maxExt = maximum extension.

changes in the value with incremental step. This did not reach statistical difference (p = 0.14 at the catch and p = 0.29 at finish when time points A and B were compared). Lumbo-pelvic ratio values at the finish were more consistent than at the catch at both time points across incremental steps, this being particularly the case for time B, (Figure 3).

Handle movement

The initiation of movement of the handle towards the body (hands forward) and the point at which the handle ceased moving towards the ergometer flywheel and started moving away from the flywheel (hands away) were examined. Hands away initiation occurred earlier at time B. Both demonstrated that this movement occurred later with each incremental step ($p < 0.001$). For example, at time A and step 2 it occurred at 32% of the stroke (35.4% at time B). This increased to 29.7% at step 4 (33.3% at time B). However, the initiation of "hands forward" demonstrated less consistency between time points and steps. For example, for step 2 it occurred at 96.9% and 96.6% of the stroke for time A and time B, respectively. At step 4 it occurred at 97.1% 96.3% at time A and time B, respectively.

Discussion

Fiskerstrand and Seiler (2004) noted that international rowers undergo intense training. Traditionally the athlete's response to this training have been recorded using physiological parameters including lactate threshold with increased tolerance indicative of training adaptation. Enhanced rowing performance is associated with improved lactate exchange and removal abilities. However, whether such physiological changes are associated with changes in the biomechanics of the rowing stroke is not known. This study focused on whether biomechanical parameters of technique measured during performance testing change with time. Further studies will be required to ascertain what these changes are related to; they may relate to direct coaching issues, strengthening strategies or changes

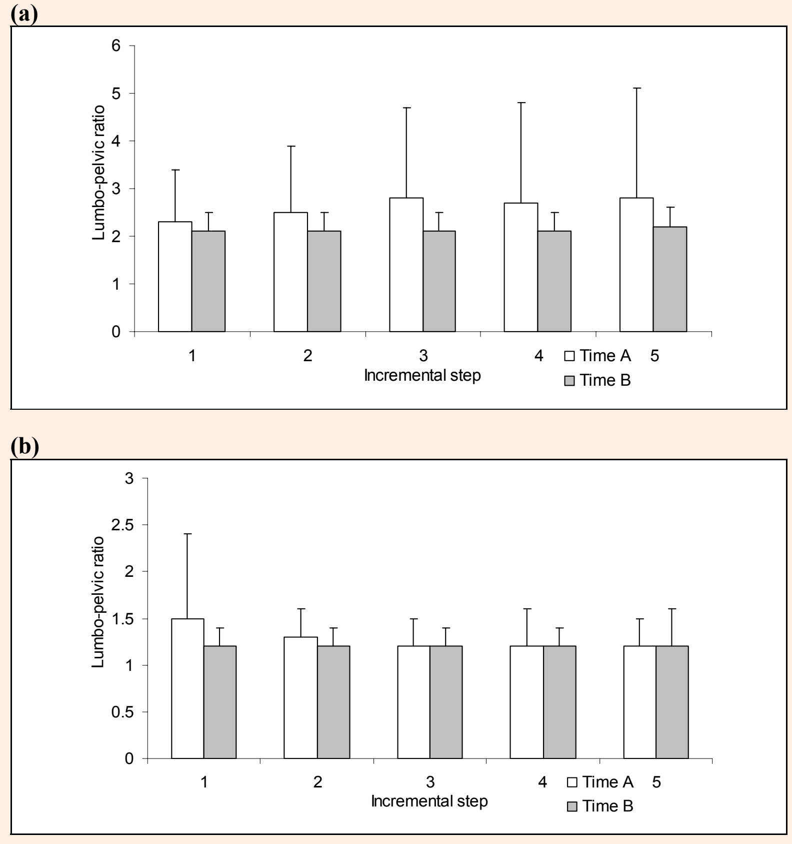

Figure 3. Changes in lumbo-pelvic ratio during the incremental step test (n=7), at the catch position (a), at the finish position (b).

related to; they may relate to direct coaching issues, strengthening strategies or changes in physiological performance.

Stroke length has previously been related to high level rowing performance (Holt et al., 2003, Thompson, 2005), thus the observed increase in stroke length amongst this group of athletes would suggest a rise in performance which was observed by their coach and their medal winning ability which rose from making race finals to winning races (2 silver medals and 1 bronze at the Athens Olympics). Associated with this is greater consistency in stroke length and suggestions of more efficient stroke profiles as indicated by the earlier completion of the drive phase. Also, peak force and power were seen to rise over the 2 year period by 80 N. Bourdin et al (2004) suggested that peak power output is the best predictor of overall rowing ergometer performance with direct correlations to VO_{2max} and rowing gross efficiency. A more efficient stroke is further supported by the fact that the stroke length and force has increased, leading to a rise in power for the same physiological work load. Indeed the associated performance lactate testing findings suggested that for each given workload the work performed at 2mM and 4mM increased by 13.8W and 17.0W respectively suggesting that for the same physiological cost greater work was performed i.e. the rowers were more efficient, rather than unconsciously pulling a harder stroke rate.

Soper and Hume (2004) suggested that body segment velocities influence performance, particularly boat velocity. Whilst segment velocities have not been analysed, aspects of body kinematics have been shown to change, in particular lumbo-pelvic kinematics. These changes focus around the use of the pelvis during the rowing stroke with a progression over time to greater anterior rotation of the pelvis at the catch. This facilitates an improvement in lumbar spine range and resultant stroke length, suggesting that the improvements in stroke length may be attributable to better lumbo-pelvic kinematics. When considered in terms of lumbo-pelvic ratio this suggests a straighter trunk position which previous authors have indicated may be beneficial (McGregor et al., 2005; Reid and McNair 2000; Stallard 1980). Poor lumbo-pelvic rotation was identified as a limitation of technique in novice rowers (McGregor et al., 2004) and poor pelvic rotation may lead to an increased loading at the junction of the lumbar spine and pelvis, with loading of the spine in rowers being an area of concern (Bahr et al., 2004; Morris et al., 2000; Reid and McNair 2000). Alterations in lumbo-pelvic motion have also been noted in rowers with and without low back injury (McGregor et al., 2003; O'Sullivan et al., 2003), and altered hamstring-quadriceps ratios have been noted in rowers with low back pain a factor which may also influence pelvic motion (Koutedakis et al 1997)

Greater consistency was observed in spinal kinematics at the finish position, a factor which will again contribute to the improved stroke length observed. In novice rowers, a tendency to slouch at the finish position was noted, depicted by an excessive posterior rotation of the pelvis (McGregor et al., 2004). This was not the case at either time A or B as can be seen from the lumbo-pelvic ratio data, which suggested improved control of the finish position at time B. This would suggest that the changes in stroke efficiency may be in part related to these changes in musculoskeletal mechanics.

Few differences were observed with timings of handle movement and thus hand position between time A and time B. Bompa in 1980 suggested that elbow position impacted on force transmission through the handle, noting that extending the elbows during the drive whilst keeping them in at the trunk at the finish generated greater force. Such changes were not investigated in these athletes.

Conclusion

In conclusion, this study demonstrates that rowing technique changes with time. The reasons for such changes could be attributed to a variety of sources including coaching, changes in strength, improved neuromuscular coordination and training programmes, as well as changes in overall physiology of the athletes concerned. Of particular interest was the suggested increased biomechanical efficiency for the same physiological workload suggesting future work should focus on integrating the biomechanical and physiological variables more closely.

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Key points

- Kinematics of rowing technique change with time and reflect improvements in performance
- Improved kinematics appear to be associated with improved rowing efficiency
- Improvement in stroke length linked in part to improvements in lumbo-pelvic technique.

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