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Research article

Changes in rowing technique over a routine one hour low intensity high volume training session

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Abstract

High volume low intensity training sessions such as one hour rowing ergometer sessions are frequently used to improve the fitness of elite rowers. Early work has suggested that technique may decline over this time period. This study sought to test the hypothesis that "elite rowers can maintain technique over a one hour rowing ergometer session". An electromagnetic device, in conjunction with a load cell, was used to assess rowing technique in terms of force generation and spinal kinematics in six male elite sweep oarsmen (two competed internationally and the remainder at a club senior level). All subjects performed one hour of rowing on a Concept II indoor rowing ergometer using a stroke rate of 18-20 strokes per minute and a heart rate ranging between 130-150 beats per minute, following a brief 5 minute warm-up. Recordings of rowing technique and force were made every 10 minutes. The elite group of rowers were able to sustain their rowing technique and force parameters over the hour session. Subtle changes in certain parameters were observed including a fall in force output of approximately 10N after the first seven minutes of rowing, and a change in leg compression of three degrees at the end of the one hour rowing piece which corresponded with a small increase in anterior rotation of the pelvis. However, it is unclear if such changes reflect a "warm-up" effect or if they are indicative of early signs of fatigue. These findings suggest that low intensity high volume ergometer rowing sessions do not have a detrimental effect on the technique of a group of experienced and highly trained rowers.

Key words: Kinematics, fatigue, force curve profiles, competition level.

Introduction

Performing at an elite level of rowing requires fitness and strength combined with high levels of skill and coordination. To optimise the speed of the boat over a given distance involves optimising the performance and training of the rower to develop technical skill, strength and endurance, as well as optimising the boat moving through the water. From the perspective of the rower, injury is one of the major contributors to a change in performance. However, as rowing is a low impact sport the risk of major injury is small (Hickey et al., 1997). One of the most common injuries reported by rowers is low back pain (Hickey et al., 1997; Stallard, 1980, Teitz et al., 2002), and although this cannot be classified as a major injury it can lead to missed training, reported to be on average 24 days a year (Bernstein et al., 2002), an inability to compete, and crew disruption (Budgett and Fuller, 1989). Injury also changes rowing technique (O'Sullivan et al., 2003).

Several authors have speculated that the high rate of injuries in rowing is a result of the high magnitude of compressive forces and moments acting on the spine (Caldwell et al., 2003). Some would consider that these high forces and their repetitive nature create excessive motion in the spine as a result of the changes in the visco-elastic tissues (Cholewicki and McGill, 1996; Panjabi et al., 1989), whilst others speculate that increased bending of the spine may occur as a result of fatigue in the back muscles (Dolan and Adams, 1998). As rowing is an endurance sport and one that is associated with repetitive movements and large loads all of these hypotheses may be relevant. Other factors that may be associated with injuries include muscle strength, endurance and fatigue (McGregor et al., 2004a), and poor technique (Holt et al., 2003; McGregor et al., 2004b). However, there may also be extrinsic mechanisms contributing to the high rate of back pain including changes in the design and materials used in the manufacture of rowing boats and blades, and the heavy use of rowing simulators or ergometers. Many have incriminated land training tools and in particular the use of the rowing ergometers (Bernstein et al., 2002; Teitz et al., 2002) with respect to back injuries in rowers, particularly as it is not uncommon for rowers to train for periods of up to 90 minutes on these ergometers (Fiskerstrand and Seiler, 2004). Research amongst club level rowers suggested that rowing technique during an hour long ergometer session did change potentially increasing the load through the lower spine and this change was attributed to fatigue (Holt et al., 2003). However, it could be speculated that experienced athletes who have undergone endurance training may not show such marked effects. This study sought to investigate this further by monitoring rowing technique in a group of experienced rowers who competed for their University Team and country at an under 23 age level. The aim of this study was to test the hypothesis that experienced athletes who have undergone endurance training will maintain their rowing technique during an hour training session at a standard intensity rating.

Methods

Study population

Six elite male sweep rowers (mean ± SD age 21.7 ± 1.7 years, mean height 1.92 ± 0.06 m, mean weight 89.6 ± 6.8kg) were recruited from the University's rowing club and written informed consent was obtained. Two of the athletes were competing at an international level. Four of the six rowers rowed bow side, the remainder stroke side.

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All were in full training at the time of the study which occurred prior to the start of the competitive rowing season. Two athletes reported previous back problems that had affected either their rowing or training in the past, but none had had any problems in the year prior to the study. All routinely performed one hour rowing ergometer sessions as part of their training.

Assessment of spinal kinematics and force

The Flock of Birds (Ascension Technology, Burlington, Vt, USA), an electromagnetic motion analysis system, which comprises of a transmitter capable of tracking the position and orientation of a series of receivers, was used to assess the kinematics of the thigh, pelvis and back during rowing. For recording the kinematics of the rower, three receivers were utilised, one positioned at the thoraco-lumbar (i.e., spinous process of T12) to record motion of the lumbar spine segment, one at the lumbo-sacral (i.e., the spinous process of S1) junction to record pelvic rotation and one at the mid point between the lateral femoral epicondyle and the greater trochanter to record thigh motion as previously described by Bull and McGregor (2000). A fourth receiver was placed on the handle to determine stroke length and handle position (Holt et al., 2003). Using a custom written programme the motion analysis system was synchronised with a load cell (Oarsum, NSW, Australia) incorporated into the handle of the ergometer (Holt et al., 2003). This allowed the determination of the start of the rowing stroke at the catch when force was generated at the handle and the measurement of force output during testing. The repeatability and validity of this system has been previously described (Bull and McGregor, 2000; Steer et al., 2006).

Testing protocol

A five minute warm-up was performed by all subjects on a Concept II indoor rowing ergometer (Model C, Morrisville, Vt, U.S.A.) using their normal rowing style, following which the position of the receivers were checked and corrected if necessary. The subjects were then asked to perform one hour of constant rowing at their utilisation-2 intensity, which for most athletes corresponded to rating 18-20 strokes per minute with a heart rate of approximately 130-150 beats per minute. This is a standard intensity used during such long ergometer training sessions amongst rowers (Thompson, 2005). During the hour test period six five minute recordings of technique were made with the athlete's knowledge; A) at 2-7 minutes into the session; B) at 14-19 minutes; C) at 24-29 minutes, D) at 32-37 minutes; E) at 44-49 minutes; and F) at 49-54 minutes. This eliminated any acceleration or deceleration at the start and end of the rowing recording periods.

Data collection and analyses

Using a custom computer programme written in C++, the load cell and Flock of Birds were synchronously sampled at 35 Hz. These data were then run through a custom analysis programme that used the force data to detect the catch of each stroke and described the stroke in terms of percentage points with 0% representing the catch and 100% representing the return to the catch. It was not necessary to filter the data recorded. The programmed defined the catch as the point of tensile force onset which was set at a threshold of 30Nforce at the handle, which has been noted to be a repeatable measure of the catch based on the work of Bull and McGregor (2000) and Holt et al. (2003). The finish was defined as the point at which tensile force production ceased (defined as force below 30N). A further programme calculated the average stroke data for each percentage point of the stroke in each recording.

The following derived data were determined for each rowing sample taken over the one hour period: peak force, work done through the stroke, power (work done divided by time of the stroke), stroke length (defined as the maximum horizontal travel of the handle) and handle height. The point at which different phases of the stroke occurred were extracted, including where peak force was achieved and when the drive phase ended. The kinematic variables examined included the angle of the femoral sensor (representing flexion-extension of the thigh), lumbosacral sensor (representing pelvic rotation about the frontal plane) and thoracolumbar sensor (representing lumbar spine flexion and extension) at the catch and finish positions and at the maximum angle and position in the stroke. Finally the ratio of lumbosacral motion to thoracolumbar motion recorded where a value of 1 demonstrates equal contributions of each body segment to the forward or backward motion of the trunk, greater than one a predominance of lumbar motion and less that 1 a predominance of pelvic motion (McGregor et al., 2005). This ratio was determined at the catch and finish positions.

Statistical analyses

The six different rowing samples taken over the one hour session were compared using repeated measures ANOVA with the Tukey's post hoc test being performed to locate where the differences lay, athlete data were paired and rowing time point was the variable of interest..

Results

An example of the average data output obtained after processing is provided in Figure 1, and shows a similar pattern of lumbar and pelvic rotation through the stroke although these are at different magnitudes, and the typical pattern of thigh flexion/extension observed by previous studies.

Force output

Table 1 summarises the stroke profile and forces curve characteristics during the one hour rowing piece. Athletes were requested to maintain a stroke rate of between 18-20 strokes during the session and it can be seen that this was achieved, although there was a tendency for this to increase non-significantly towards the end of the hour rowing, 17.9 ± 0.4 strokes per minute at the start of the hour increasing to 18.7 ± 0.6 towards the end of the hour. No significant differences were observed in any of the average force output variables throughout the hour of testing, there may however, have been differences in stroke profiles but analyses was restricted to an average stroke over each recorded time period. Stroke length appeared to be the most consistent parameter showing minimal if any changes with time tending to be between 164-166cm.

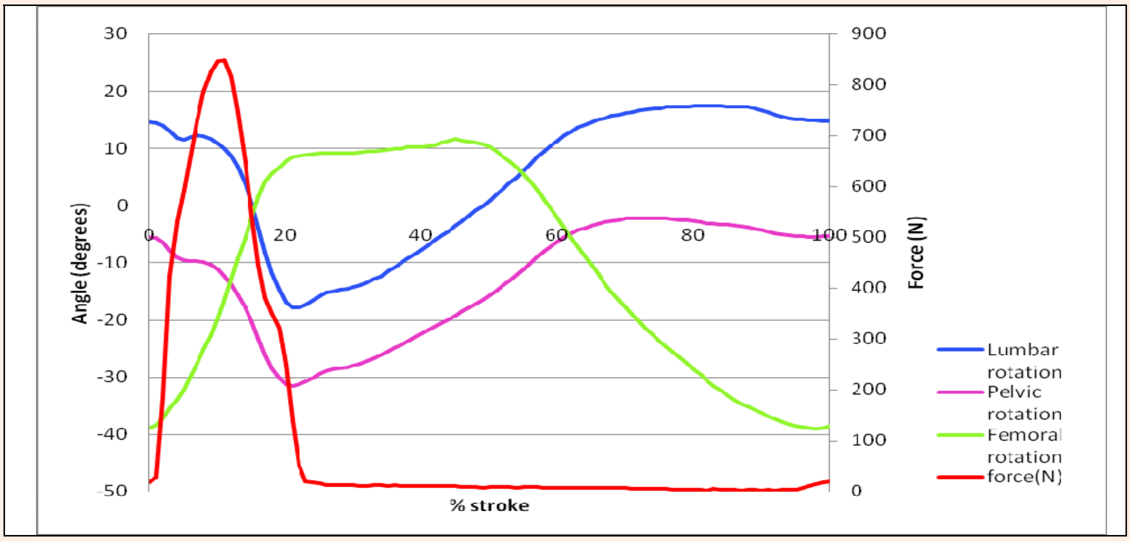

Figure 1. An example of processed data output from one subject taken at the 4th testing interval.

Peak force was observed to fall by approximately 10 N between the first sample point at 2-7 minutes into the piece and the second sample point at 14-19 minutes into the rowing piece, with a further subsequent fall and then stabilisation until the end of the rowing piece. This was also reflected in work done but less so in power output, the effect on power may reflect the changes with respect to when the peak force was generated and the later onset of the end of the drive.

Thigh flexion/extension

The data on thigh flexion/extension during the stroke revealed that there were no significant changes with time (see Table 2). However, a number of trends were observed including a slight reduction in thigh flexion/extension at the catch with time, with the legs compressing around 3 degrees less at the end of the hour piece. This was associated with an increase in femoral extension of 3 degrees at the finish, which links with the observation on the increased time spent on the drive phase on the stroke indicated by percentage stage end of the drive, see Table 1.

Sacral rotation (pelvic rotation)

Again no significant changes in any of the sacral parameters were observed over the hour rowing piece (Table 3). There were however subtle increases in anterior rotation of the pelvis at the catch and posterior rotation at the finish, which correspond to the changes in flexion and extension observed in the thigh data and the maintenance of stroke length described earlier.

Lumbar rotation (lumbar spine flexion/extension)

No significant changes were observed with respect to lumbar spine kinematics, see Table 4) however small changes were seen over the course of the 1 hour rowing piece. As with pelvic rotation at the catch a subtle increase in lumbar was observed with time, and at the finish as with posterior pelvic rotation greater extension of the lumbar spine was observed.

Lumbo-pelvic ratio

No significant differences were seen in the lumbo-pevic ratios over the 1 hour rowing piece. At the start of the hour, the lumbo-pelvic ratio was 3.4 ± 1.7 at the catch, and 0.8 ± 0.5 at the finish; An increase was observed at 14-19 minutes, time point B, at the catch increasing to 3.8 ± 2.0 but little change was seen at the finish 0.84 ± 0.3. The catch ratio did change however, over the hour falling to 3.0 ± 1.2 at time point F (54-59 minutes into the rowing piece). These changes were not significant but do follow the patterns seen with respect to a reduction in thigh flexion and extension and subtle increase in both pelvic and lumbar rotation/ flexion.

Table 1. Changes in the force curve profile and stroke profile during the 6 time points. Data are means (±SD, n=6).

Time interval	A (2-7 min)	B (14-19 min)	C (24-29 min)	D (32-37 min)	E (44-49 min)	F (54-59 min)
Stroke rate	17.9 (.4)	18.1 (.6)	18.2 (.7)	18.4 (.7)	18.5 (.7)	18.7 (.6)
Peak force (N)	904 (125)	900 (128)	892 (129)	887 (127)	899 (131)	888 (118)
% Stroke when peak force occurs	10.3 (1.5)	10.8 (1.6)	11.0 (1.9)	11.0 (1.9)	11.6 (1.5)	11.0 (2.0)
% Stroke when end of drive occurs	21.5 (2.3)	22.3 (2.1)	22.7 (2.3)	22.5 (2.1)	23.0 (2.5)	23.2 (1.9)
Stroke length (cm)	164.2 (5.4)	165.4 (4.8)	165.8 (4.8)	165.6 (4.5)	166.0 (5.0)	165.6 (4.6)
Power (W)	254.5 (17.9)	255.3 (15.5)	255.6 (14.6)	256.5 (15.4)	257.9 (17.3)	260.4 (18.9)

Work done (J)	21.5 (2.3)	22.3 (2.1)	22.7 (2.3)	22.5 (2.1)	23.0 (2.5)	23.2 (1.9)

Table 2. Changes in thigh flexion and extension during the 6 time points. NB movements into flexion negative, movements into extension positive. Data are means (±SD, n=6).

Time interval	A (2-7 min)	B (14-19 min)	C (24-29 min)	D (32-37 min)	E (44-49 min)	F (54-59 min)
Thigh flexion/extension at the catch (°)	-28.7 (4.0)	-29.1 (5.9)	-29.0 (7.0)	-28.5 (7.6)	-27.7(8.9)	-25.7 (8.9)
Maximal thigh flexion/extension (°)	-29.8 (4.1)	-30.1 (6.0)	-30.1 (7.1)	-29.6 (7.7)	-29.1 (8.9)	-27.0 (8.9)
% stroke where maximal thigh flexion/extension occurs	95.7 (5.4)	95.5 (5.2)	96.2 (4.7)	96.0 (4.6)	95.4 (4.7)	96.0 (4.8)
Femoral extension at the finish (°)	14.5 (4.5)	16.0 (4.7)	16.6 (5.7)	17.0 (6.7)	19.7 (7.4)	21.5 (8.1)
Maximal femoral extension (°)	17.7 (2.4)	18.5 (2.3)	19.1 (3.5)	20.0 (4.0)	22.0 (5.3)	23.4 (6.5)
% stroke where maximal femoral extension occurs	22.3 (4.3)	22.3 (4.5)	22.8(4.5)	22.8 (4.5)	23.0 (4.5)	22.8 (3.9)

Discussion

This study explored the effect of one hour ergometer rowing on rowing technique in a group of elite experienced athletes. These large volume low intensity sessions on the ergometer are common place in the training schedule of elite athletes (Fiskerstrand and Seiler, 2004) and whilst they aim to improve stamina and endurance early work has suggested that in some athletes the effects of fatigue may become apparent during the hour as reflected in a change in rowing technique (Holt et al., 2003) and that this in turn may contribute to injury.

Holt et al. (2003) observed differences between the start of the hour rowing session and the end, and the results indicate greater use of the lumbar spine towards the end of the rowing piece which were attributed to fatigue. Unlike this earlier study, no significant changes were observed over the hour in the current study. This in part may be due to the different population of athletes used and their greater familiarity and experience with one hour ergometer sessions. Indeed Seifert et al. (2007) noted that elite swimmers had more stable kinematics than swimmers of a lower standard suggesting that experience and ability may explain the differences observed in the studies. In contrast, research into the kinematics of golfers noted changes in swing kinematics after forty minutes of putting and these changes were attributed to fatigue in the erector spinae muscles of the trunk (Benjaminse et al., 2008; Evans et al., 2008). Other studies have noted similar changes in task mechanics and kinematics as a result of fatigue (Gates and Dingwell, 2008). Low levels of endurance and fatigue have been previously noted in rowers (McGregor et al., 2004a) which would align with both Evans et al.'s (2008) findings in golfers and Holt et al.'s (2003) findings in rowers but not the current study. However, it is noted that changes in the training of rowers with respect to trunk muscles have been noted (Chan, 2005; McGregor et al., 2007; Tse et al., 2005).

However, Holt et al. (2003) utilised only four data sample points during the testing; one at the start (minutes 1-2), 20 minutes, 40 minutes and one at the end. In contrast this study performed six data samples, one every 10 minutes with the first measure at 2-7 minutes, suggesting that some changes may be exaggerated by the shorter recording time, and at minutes 1-2 the athlete may still have been "settling" into their technique – thus the differences observed between this time point and subsequent sample points. This would indicate the need for a more comprehensive warm-up period. Whilst peak force appeared to decline in the current study, power increased and perhaps this was due to the subtle changes in technique and gradual improvement in lumbo-pelvic ratio over the time piece perhaps again stressing the need for a good warm-up period. Lumbo-pelvic motion has previously been indicated to be important to rowing technique and performance (McGregor et al., 2007). However, more research on a larger group of athletes over a longer time period is required to differentiate the effect of warm-up from the effect of technique deterioration as a result of fatigue.

Table 3. Changes in pelvic rotation during the 6 time points. NB anterior rotation of the pelvic denoted by positive angles, posterior by negative. Data are means (±SD, n=6).

Time interval	A (2-7 min)	B (14-19 min)	C (24-29 min)	D (32-37 min)	E (44-49 min)	F (54-59 min)
Anterior rotation at the catch (°)	12.2 (5.7)	11.1 (5.0)	12.0 (5.1)	12.2 (5.0)	13.2 (5.9)	13.1 (5.3)
Posterior rotation at the finish (°)	-18.9 (9.8)	-23.7 (9.4)	-24.3 (10.4)	-24.4 (11.4)	-25.2 (11.4)	-26.3 (10.4)
Maximum anterior rotation (°)	14.4 (4.8)	13.7 (4.3)	14.4 (5.2)	14.6 (5.0)	15.5 (5.5)	15.4 (5.5)
% stroke where maximal anterior rotation occurs	89.0 (15.4)	88.5 (14.1)	88.7 (13.9)	88.5 (13.8)	87.0 (15.2)	88.3 (14.0)
Maximum posterior rotation (°)	-29.2 (10.1)	-32.6 (10.2)	-33.5 (11.4)	-34.2 (11.5)	-34.6 (13.1)	-34.9 (11.3)
% stroke where maximal posterior rotation occurs	30.8 (3.2)	31.2 (3.3)	31.7 (3.5)	32.0 (3.7)	31.4 (3.7)	31.8 (3.0)

Table 4. Changes in lumbar rotation during the 6 time points. NB lumbar flexion is denoted by positive angles, extension by negative. Data are means (±SD, n=6).

Time interval	A (2-7 min)	B (14-19 min)	C (24-29 min)	D (32-37 min)	E (44-49 min)	F (54-59 min)
Flexion at the catch (°)	33.6 (7.0)	33.9 (6.8)	34.5 (6.7)	34.5 (6.8)	35.8 (7.0)	34.9 (7.2)
Extension at the finish (°)	-13.5 (8.0)	-18.1 (5.9)	-18.8 (6.5)	-18.3 (5.8)	-18.7 (5.8)	-20.2 (4.7)
Maximum flexion in stroke (°)	35.3 (7.1)	35.8 (7.0)	36.3 (7.0)	36.3 (7.0)	37.6 (7.1)	36.8 (7.5)
% stroke where maximum flexion occurs	92.7 (10.2)	93.2 (10.0)	93.3 (10.1)	93.3 (10.1)	92.4 (11.0)	93.0 (10.4)
Maximum extension in stroke (°)	-31.4 (6.3)	-36.0 (5.2)	-37.8 (6.2)	-37.8 (5.0)	-36.5 (5.3)	-36.4 (5.4)
% stroke where maximum extension occurs	31.8 (1.7)	32.2 (1.5)	32.7 (1.6)	32.8 (1.9)	32.2 (3.1)	32.7 (2.9)

Previous work on the role of "warm-ups" has suggested that it improves joint proprioception (Bartlett and Warren 2002) which may account for the improvement in lumbar spine and pelvic motion observed in the current study. It has also been suggested that warm-up can optimise the biomechanics of a muscle (Safran et al., 1988). However it is less clear what degree of warm-up athletes perform prior to an hour training session and whether or not most athletes simply incorporate this into the training session itself. In the current study a five minute warm-up was enforced in contrast to the previous three minute warm-up used in the prior study. This again may have impacted on the differences observed between studies.

Conclusion

To conclude, this study suggests that elite athletes are able to perform long ergometer training sessions with no changes in their technique. This may be a reflection of adaptation to such sessions and their background training in the sport over a number of years. This is supported by Seifert et al.'s (2007) findings in swimmers. However, there does appear to be a settling in period and as such warm-up may need to be more substantial than 3-5 minutes.

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Key points

- Elite rowers do not demonstrate changes in rowing kinematics over and hour rowing piece.
- Rowers require an adequate warm-up to establish their technique.

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