Differences in Spinopelvic Kinematics in Sweep and Scull Ergometer Rowing

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Objective: The spinopelvic kinematics of sweep and scull have yet to be investigated, despite evidence suggesting that sweep rowing may be provocative for low back pain (LBP). The aim of this study was to determine whether differences existed in spinopelvic kinematics in high-level rowers without LBP in sweep and scull ergometer rowing.

Design: Repeated measures study.

Setting: Institute of Sport Laboratory.

Participants: Ten high-level rowers.

Interventions: Kinematics of the pelvis, lower lumbar, upper lumbar, and lower thoracic regions during the drive phase of the rowing stroke were measured while rowing on an interchangeable sweep/scull ergometer.

Main Outcome Measures: Total and segmental spinopelvic kinematics.

Results: Sweep rowing showed greater lateral bend ($P < 0.05$) throughout the stroke, which was predominately due to movement of the upper lumbar and lower thoracic regions. Furthermore, sweep rowing displayed a greater magnitude ($P < 0.05$) of axial rotation at the catch (created at the pelvis). Both sweep and scull rowing showed values close to end range flexion for the lower lumbar spine at the catch and early drive phases. No difference ($P > 0.05$) was evident in lateral bend or axial rotation values for the lower lumbar region.

Conclusions: Some differences exist in spinopelvic kinematics between sweep and scull ergometer rowing. However, it may be speculated that the lack of differences in lateral bend and axial rotation at the lower lumbar spine in sweep rowing may represent an adaptive and protective approach of experienced rowers. This may be the focus of future research studies.

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INTRODUCTION

The sport of rowing involves 2 distinct stroke types called sweep and scull. Regardless of the subdiscipline, each of these rowing strokes consists of 4 phases: the catch, drive, finish, and recovery (Figure 1). In sculling, the rower uses 2 oars to propel the shell (1 each side of the rower), whereas in sweep rowing the rower uses only 1 oar that can be placed on either the starboard (right) or port (left) side.

Both training and testing of rowers of all performance levels is routinely conducted on rowing ergometers[1,2] because they provide protection from the weather and a controlled environment for training and testing. Although previous research has shown differences in upper limb kinematics,[3] energy expenditure,[4] and physiological responses[5,6] in on-water and ergometer rowing, other research has shown similar body positions at the catch and finish when comparing ergometer with on-water sculling.[7]

Low back pain (LBP) is a common complaint among rowers,[8–13] and it is not entirely clear why this is the case; however, factors such as training volume, muscle recruitment patterns,[14,15] weight training,[13] poor technique,[16,17] ergometer training,[13,18] and spinal kinematics[2,10,13,14,19,20] have been the subject of previous examination. There has been previous debate on whether sweep rowing increases the risk of LBP when compared with scull rowing[8,10]; however, differences in spinal kinematics and differences between these 2 stroke types have yet to be investigated. Specifically, whether differences exist with reference to end-range in flexion, compression, and/or rotation is unknown. A contributing factor for the lack of research in this area may be that ergometers have typically been center-pull devices, which are representative more of on-water sculling.[1,2,21] However, a newly developed interchangeable sweep/scull ergometer (Innovative Rowing Solutions; OarTec, Sydney, New South Wales, Australia) makes the investigation of spinal kinematics in sweep and scull rowing possible.

Although previous research has examined trunk kinematics in rowing, these findings have been limited to planar movements,[2,14–16,18,21,22] but out-of-plane movements have not been examined. This was noted by McGregor et al,[21] who raised the question of whether rotational and bending moments associated with sweep-style strokes may increase

FIGURE 1. The 4 phases of the rowing stroke. Phases included are the catch (A), drive (B), finish (C), and recovery (D).

the risk of injury and also questioned where these movements may actually occur. From previous research conducted on center-pull ergometers, it has been shown that the lower lumbar spine is flexed at the catch phase and remains flexed into the drive phase.[14,22,23] With reference to the end of range of motion (ROM), the trunk has been shown to reach between 75% and 90% of maximum ROM,[23] and in subjects with LBP, the time spent near end range is greater and the lower lumbar spine reaches closer to end range.[14] This research has allowed comparison of kinematics at varying stroke rates[19] and work intensities,[22] during prolonged ergometer trials,[18] and has also evaluated good and bad techniques.[16] To date, however, there are no kinematic studies that have examined spinopelvic motion in the sweep stroke, taking into account the out-of-plane movements such as axial rotation and lateral bend. There also exists no comparative data between the 2 rowing styles of sweep and scull rowing, and none within a high-level rowing group. Finally, as the kinematics of the thoracolumbar spine vary in its distinct regions[24] and differences in posture of the lower and upper lumbar spine have been found in sitting[25] and rowing,[14] a multisegmental approach to examining spinopelvic kinematics is needed.

Therefore, the aim of this study was to examine differences in spinopelvic kinematics rowers without LBP in both the sweep and scull rowing strokes while rowing on an ergometer. This study was conducted in a group of high-level rowers to ensure technical proficiency in both stroke types.

METHODS

Participants and Experimental Protocol

Ten junior and senior rowers (5 men and 5 women) without LBP from a high-level rowing squad were recruited for this study. Participants had a mean (SD) age of 19.1 (2.1) years, height of 1.84 (0.10) m, mass of 80.0 (12.6) kg, and had rowed for 5.7 (2.0) years. Five rowers primarily rowed scull and 5 rowers primarily rowed sweep; however, all participants were deemed to be technically competent in both forms of rowing by the Institute of Sport rowing coaches. At the time of testing, the participant must have been a member of the Institute of Sport rowing squads. Other inclusion criteria included an absence of LBP and participants must not have received treatment for a lower back complaint within the 3-month period before testing. This study was approved by the Institutional Human Research Ethics Committee of Edith Cowan University, and informed written consent was provided by all participants.

Participants completed spinopelvic ROM trials (as described below) followed by a standardized warm-up. The warm-up included a familiarization period to allow the adjustment of foot straps and feet height, and also the development of a comfortable rowing rhythm. A 1-minute period was given to allow the rower to attain the correct rowing rate and rhythm before collection of data. This period was allowed for each adjustment of stroke rate and when changing between stroke styles. Participants then completed the sweep and scull ergometer trials in a randomized order. At the commencement of the trial, participants rowed at 18 strokes per minute (spm) for 4 to 5 minutes. During the second, third, and fourth minute of each trial, synchronized spinopelvic kinematics and oar angle data were recorded for 7 to 8 strokes. This process was repeated when stroke rate was increased to 22 and 26 spm. Stroke rate was initially monitored but confirmed via later analysis. A total of 18 trials (2 rowing types/3 stroke rates per condition/3 trials per stroke rate) were collected for each participant. For sweep rowing, an equal number of subjects preferentially rowed on the port and starboard sides.

Data Collection

The rowing ergometer was instrumented with 2 multiturn potentiometers directly attached to the rotational pins of the ergometer. This allowed quantification of oar-handle kinematics, catch and finish positions, and calculation of real stroke rate. Before testing, potentiometers were calibrated at 3 points, they were at –45° (oar handle(s) near the catch), 0° (a line between the ergometer's "oarlocks"), and +45° (oar handle(s) near the finish). These 3 angles were represented using a precision-made calibration frame, and a linear calibration function converted measured voltages to angles.

Before data collection, the ergometer was set up to replicate the individual athlete's on-water rigging. This involved setting the pin span and oar inboard to within 0.5 cm of the boat settings, as well as the ensuring pivot (gate) height allowed for a finish position closely matching that experienced on-water. These adjustments were carried out by a rowing biomechanist with 15 years of experience as a rowing coach. Foot position, both height and lateral distance, was also adjusted by the athlete to replicate in-boat positioning.

Spinopelvic Kinematics Data

Spinopelvic kinematics data during ROM and rowing trials were collected using the 3-Space Fastrak (Polhemus Navigation Science Division, Kaiser Aerospace, Colchester, Vermont). This device consists of an electromagnetic source and 4 sensors and is known to have an accuracy of 0.2°[26] and is

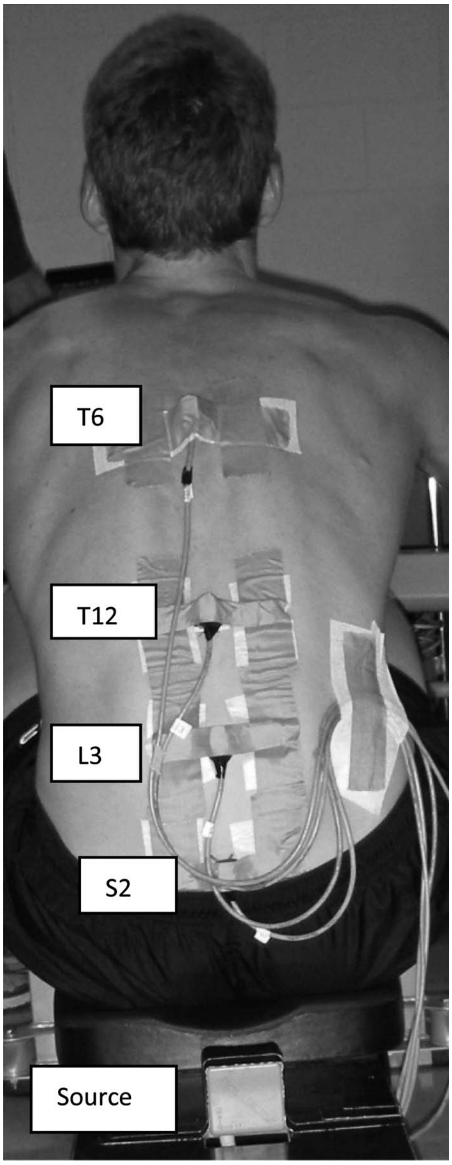

FIGURE 2. Placement of the sensors from the 3-Space Fastrak on a rower during testing.

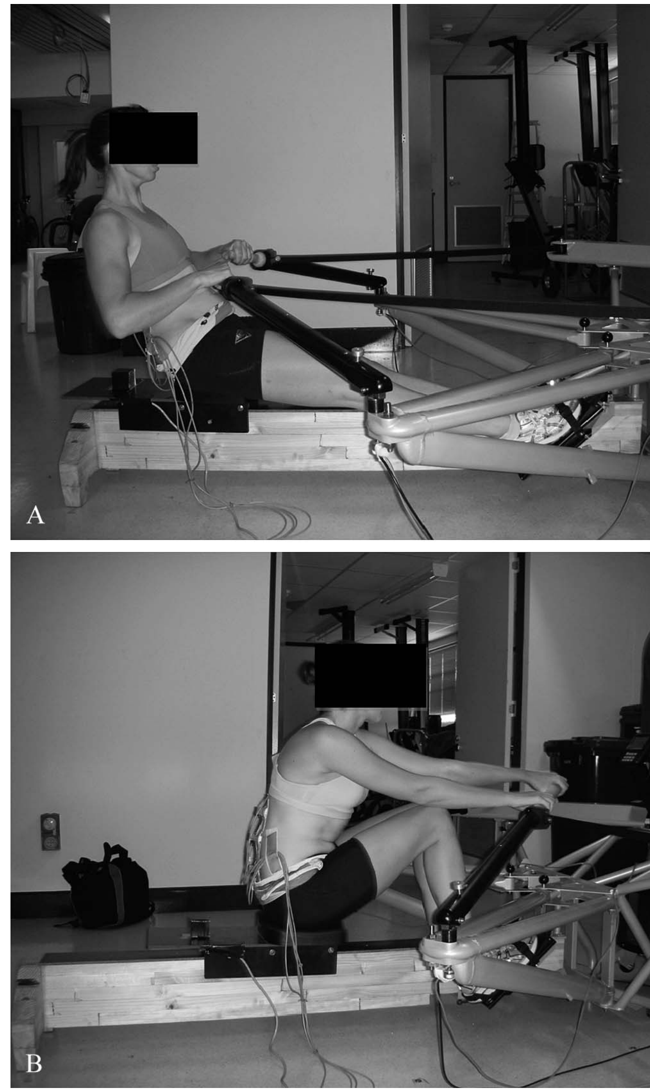

FIGURE 3. Participant shown on the modified rowing ergometer at the scull rowing type (finish phase) (A) and sweep rowing type (catch phase) (B).

known to be valid and reliable.[26,27] Because the ergometer contains a slide with high ferrous content (which influences data accuracy), the slide and the ergometer's footings were replaced with wooden components of identical dimensions.[28]

The Fastrak's sensors were mounted over the spinous processes of T6, T12, L3, and S2 (Figure 2). Specifically, the sensors were firmly attached to plastic rulers fixed to the skin with Leukofoam adhesive and then fastened with fixomull adhesive tape and rigid sports strapping tape.[14,24] This method of attachment was used after preliminary trials conducted by 3 of the researchers (A.D.S., J.P.C., and A.F.B.). The experimental environment for scull and sweep ergometer rowing is shown in Figures 3A and 3B, respectively.

Spinopelvic ROM measurements were recorded for 5 seconds with participants positioned in a lumbopelvic sitting posture[29] with knees and hips flexed to 90°. Range of motion was measured in flexion, extension, lateral flexion, and rotation by an experienced musculoskeletal physiotherapist (J.P.C.). Each of these trials was repeated 3 times.

Spinopelvic data and potentiometer (oar-handle) data were collected at 30 Hz and 1000Hz, respectively, using a National Instruments cDAQ-9172 chassis containing 3 analog input modules (National Instruments, Austin, Texas) interfaced to a personal computer.

TABLE 1. Mean (SD) Stroke Rate Data in SPM

	18 spm	22 spm	26 spm
Sweep	17.9 (0.6)	21.6 (0.4)	25.2 (0.6)
Scull	17.7 (0.6)	21.4 (0.5)	25.0 (0.8)

TABLE 2. Mean (SD) Catch and Finish Angles for Sweep and Scull Rowing At Each Stroke Rate

	Sweep			Scull			
	18 spm	22 spm	26 spm	18 spm	22 spm	26 spm	P
Catch angle	–63.8 (10.7)	–65.3 (11.3)	–64.9 (12.3)	–76.4 (5.8)	–76.7 (6.3)	–76.5 (6.7)	0.018*
Finish angle	27.9 (4.2)	27.0 (5.1)	27.7 (6.2)	41.8 (8.8)	42.0 (9.4)	42.1 (9.3)	0.002*

All data are measured in degrees.
*Significant difference ($P < 0.05$) evident between sweep and scull rowing.

Data Analysis

The output of raw Fastrak data was in the Cardanic sequence of lateral flexion, flexion/extension, and axial rotation. To make these data more clinically meaningful,[27] these data were converted into flexion/extension, lateral bending, and axial rotation sequence order via matrix algebra procedures.[27] All spinopelvic kinematic data were referenced to a predetermined neutral spine position and were considered both absolutely and relatively (%ROM). Because there were participants who rowed port and starboard side, all data were converted to be representative of a "port" side sweep rower. This conversion to port side sweep ensured that negative and positive data values created depending on the side of sweep rowing did not offset each other in the data analysis. The following regional spinopelvic angles were defined: (1) Pelvis: S2 relative to the magnetic source, which was aligned with the ergometer's slide; (2) Lower lumbar: L3 relative to S2; (3) Upper lumbar: T12 relative to L3; and (4) Lower thoracic: T6 relative to T12.[14,28] Data were time normalized to 0% to 100% of the drive phase, and an ensemble average was created from 5 of the strokes collected. Data were extracted from 0% (catch), 25%, 50%, 75%, and 100% (finish) of the drive phase, and no recovery phase data were analyzed. All data analysis was conducted using customized software.

Statistical Analysis

To examine the repeatability between the 5 strokes used for analysis the coefficient of multiple correlation[30] was calculated. Furthermore, intraclass correlation coefficients ($ICC_{3,1}$)[31] were used to determine the repeatability of 3 trials for each rowing type and stroke rate. To determine whether differences existed between cell means, a 2-way analysis of variance (ANOVA) with 2 within-subject variables (rowing condition and stroke rate) was conducted. Before the ANOVA's being run, independent *t* tests were carried out to ascertain whether a gender effect was evident. All statistical analyses were conducted using PASW18 (SPSS Inc, Chicago, Illinois) with $P < 0.05$.

RESULTS

Mean (SD) stroke rate data (Table 1) show adherence to the requested strokes rates. Also, oar-handle data (Table 2) indicate that sculling displayed larger catch and finish angles when compared with sweep rowing ($P = 0.018$ and $P = 0.002$, respectively).

Coefficient of multiple correlation (CMC) values for spinopelvic kinematics data revealed very good to excellent between-stroke reliability (CMC range = 0.733-0.994), which justified the formation of ensemble averages. Furthermore, as all stroke rates, oar kinematics, and spinopelvic kinematic variables had good to excellent between-trial reliability (ICC range = 0.651-0.999), data for each participant were averaged.

Preliminary analysis revealed no evident gender effect ($P > 0.05$); therefore, spinopelvic kinematics data were pooled

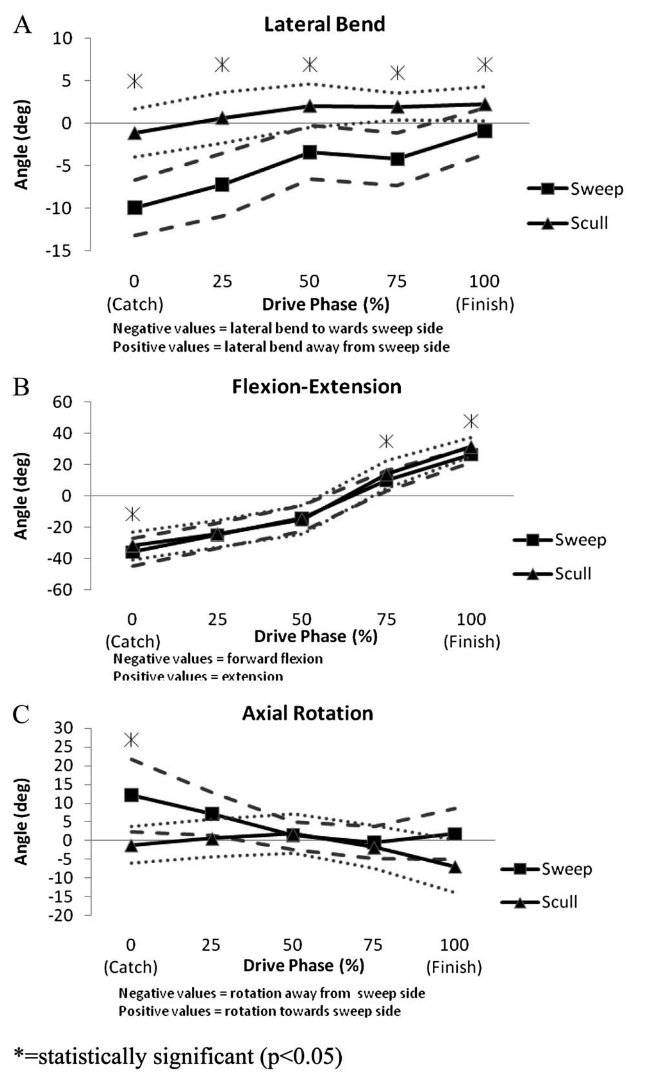

FIGURE 4. Spinopelvic data during the drive phase for the sweep and scull trials (T6 relative to source). Data are displayed for lateral bend (A), flexion-extension (B), and axial rotation (C).

TABLE 3. Summary of Significant Findings for Spinopelvic Kinematics for Sweep Versus Scull Ergometer Rowing

Total range (T6 relative to source)	
Lateral bend	Increased in sweep (toward sweep side) at catch, 25%, 50%, and 75% drive phase, and finish ($P < 0.001$, 0.001, 0.001, 0.001, 0.006, respectively)
Flexion-extension	Increased flexion in sweep at the catch ($P = 0.010$)
	Reduced extension in sweep at 75% drive phase and finish ($P = 0.004$ and 0.001, respectively)
Axial rotation	Increased in sweep (toward sweep side) at the catch ($P = 0.010$)
Lower thoracic (T6 relative to T12)	
Lateral bend	Increased in sweep (toward sweep side) at catch, 25%, 50%, and 75% drive phase ($P < 0.001$, 0.001, 0.001, and 0.003, respectively)
	Lateral bend >70% ROM at catch and 25% and 50% drive phase in sweep rowing
Flexion-extension	No significant findings
Axial rotation	No significant findings
Upper lumbar (T12 relative to L3)	
Lateral bend	Increased in sweep (toward sweep side) at 25%, 50%, and 75% drive phase, and finish ($P = 0.044$, 0.036, 0.010, and 0.011, respectively)
Flexion-extension	Flexion ≥80% ROM at catch in sweep and scull strokes
Axial rotation	No significant findings
Lower lumbar (L3 relative to S2)	
Lateral bend	No significant findings
Flexion-extension	Flexion >85% of ROM at catch and 25% drive phase in both strokes
	Flexion >80% ROM at 50% drive phase in both strokes
Axial rotation	No significant findings
Pelvic (S2 relative to source)	
Lateral bend	No significant findings
Flexion-extension	Reduced extension in sweep at 75% drive phase ($P = 0.014$)
Axial rotation	Increased in sweep (toward sweep side) at catch, 25% and 75% drive phase, and finish ($P = 0.001$, 0.021, 0.033, and 0.021, respectively)

for ANOVA. Although no significant differences ($P > 0.05$) were evident between stroke rates, several significant differences ($P < 0.05$) were observed for spinopelvic kinematic data between sweep and scull conditions. Spinopelvic kinematics data for the trunk (T6 relative to the source) are shown in Figure 4, and a summary of significant findings is provided in Table 3. Total and regional ROM data are reported in Table 4.

DISCUSSION

The aim of this study was to determine whether differences in spinopelvic kinematics were present in sweep and scull rowing in high-level rowers. Currently, there is no information comparing the spinopelvic kinematics in these rowing types.

Minimal differences were evident in flexion and extension between sweep and scull ergometer rowing. In both rowing types, the pelvis was posteriorly rotated, and both the lower and upper lumbar spine were flexed at the catch. These opposing movements create an exaggerated slumped posture. This pattern continued through to 75% of the drive phase, as seen in previous ergometer (sculling) research.[14,23] It has been previously hypothesized that low back injury risk is increased when the spine is loaded near end range flexion because this increases the loading of the passive spinal structures.[24,32,33]

The major spinopelvic kinematic differences between sweep and scull rowing were found in axial rotation and lateral bending. As may be expected, increased spinopelvic axial rotation was evident in sweep rowing, which was achieved through differences in pelvic axial rotation. These differences were seen at the catch and through subsequent phases of the rowing stroke. Sweep rowing was also associated with increased lateral bending toward the preferred sweep side at the catch. This was largely observed in the lower thoracic and upper lumbar regions and was observed throughout a majority of the drive phase. It was of interest that no

TABLE 4. Mean (SD) ROM Data for T6 Relative to Source (Total) and for the Regions Examined in This Study

	Total	Pelvic	Lower Lumbar	Upper Lumbar	Lower Thoracic
Lateral bend	43.0 (7.8)	10.0 (2.5)	17.6 (5.1)	12.4 (5.5)	3.0 (1.4)
Flexion	102.5 (19.1)	29.1 (9.2)	20.4 (5.4)	21.2 (8.6)	31.8 (14.0)
Extension	38.9 (21.0)	2.0 (7.6)	14.1 (7.6)	26.8 (17.2)	4.0 (4.5)
Axial rotation	40.4 (9.9)	12.4 (5.5)	3.0 (1.4)	3.9 (1.8)	21.1 (5.4)

All values are reported in degrees. Lateral bend and axial rotation data are a combination of left and right sides.

significant differences were evident between sweep and scull rowing in terms of axial rotation or lateral bend through the lower lumbar region. This raises further questions related to current debate as to sweep rowing increases the risk of LBP.[8,10]

In comparison with other studies examining kinematics during ergometer rowing, our study showed no difference between male and female rowers[34] and also exhibited no changes in kinematic data at different stroke rates. This lack of change between stroke rates differs from previous research conducted on club-level rowers.[19] The consistent kinematic data across variable stroke rates may be explained by the high level of the rowers recruited in this study. Consistency of kinematic data in elite rowers has been recognized in previous research; however, it should be noted that kinematics change during maximal rowing tests.[22]

As no previous studies have examined axial rotation and lateral bend kinematics in sweep rowing, we are unable to compare our findings with those of previous studies. However, our kinematic data in the flexion-extension plane showed similar findings to previous research.[2,14,23] In our study, lumbar flexion (T12 to S2) at the catch showed similar values to those found in previous work[2,18] that examined the movement of T12 relative to S1. Also, similar to previous research,[14,23] the lower lumbar spine was flexed at the catch close to end-range values (in excess of 85%) and remained flexed beyond 75% of the drive phase.

Our findings in high-level rowers without LBP may suggest that the rowing technique used by these participants (who have rowed for many years with high training volumes) protects them from LBP. This may suggest a role for kinematic analysis of rowers to monitor technique, in screening or in rehabilitation from injuries.[16,19] Future studies could be designed using a pain-ramping protocol[35] to determine differences between those with and without LBP. Further prospective studies could be conducted to determine whether those who use spinopelvic movement patterns, such as those used by the rowers in this study, are less likely to develop LBP.

This study provides an original biomechanical description of the differences between spinopelvic motion in sweep and scull rowing. However, several limitations of the study need to be mentioned. First, this study was conducted on a rowing ergometer rather than on-water due to the difficulties related to on-water collection of spinopelvic kinematics. However, the oar angle data collected suggest that these rowers have gone through a similar ROM to those on on-water.[36] Second, due to the difficulty in recruiting homogenous samples of high-level rowers, a relatively small sample of rowers were recruited. Finally, this study was only conducted on high-level rowers; therefore, our findings may not be able to be generalized to rowers of lower performance levels or even novices.

CONCLUSIONS

Sweep rowing showed significantly increased lateral bend of the trunk, primarily at the upper lumbar and lower thoracic regions. Sweep rowing also showed greater axial rotation, largely due to increased movement at the hips. The lower lumbar spine in both sweep and scull rowing was flexed to near end range and therefore shows the potential loads passing through the lower lumbar spine in both strokes.

This group of high-level rowers, however, showed no significant increase in lateral bend or axial rotation of the lower lumbar region in sweep rowing. It may be speculated that this represents a protective mechanism to minimize potentially injurious coupled motions at the lower lumbar spine. Future studies are required to evaluate this further.

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