Gender Differences in Trunk and Pelvic Kinematics During Prolonged Ergometer Rowing in Adolescents

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The trunk and pelvis kinematics of 20 healthy male and female adolescent rowers were recorded during an ergometer trial using an electromagnetic tracking system (Fastrak). The kinematics of each drive phase were collected during the 1st and 20th minute, respectively. The mean and range of the kinematics, stroke rate and stroke length were compared between genders and over time. Male rowers postured their pelvis with more posterior tilt and their thoracic spine in more flexion than female rowers \((P < .05)\). Both genders postured their pelvis in more posterior pelvic rotation and upper trunk in more flexion over time. Male rowers were found to have a significantly shorter drive phase than female rowers \((P = .001)\). Differences in trunk and pelvic kinematics between adolescent male and female rowers suggest potentially various mechanisms for biomechanical stress. Assessment and training of rowers should take gender differences into consideration.

Keywords: spinal kinematics, sports, lumbar, thoracic

Rowing is a popular sport that males and females from school age to the international level compete in. It has been reported that the trunk accounts for a large amount of the force generation that directly results in ergometer and boat linear velocity.1 This places significant stresses through the spine’s structures at end of range flexion,2 and likely contributes to the high prevalence of low back pain (LBP) consistently observed in rowers of all ages.3–5 Despite the sport’s popularity and prevalence of LBP in the adolescent age group,4,7 there is a lack of biomechanical studies on this specific population.

There is a gender disparity in injury prevalence in elite rowers; for example, LBP is the most commonly reported injury in males (25.0%) in comparison with only 15.2% in females, who are more susceptible to chest wall injuries (22.6%), which are suffered by only 6% of males.3 This disparity may reflect different risk factors between genders in rowing. Therefore, understanding performance and spatiotemporal kinematic differences between gender in adolescent rowers will allow clinicians to better manage injury risk factors, with further implications to coaches’ ability to optimize performance.4

Gender differences have been explored in elite adult populations during ergometer rowing, and differences in performance,8,9 force generation and pelvic kinematics were reported.10 Yoshiga and Higuchi (2003) reported that men aged between 18 and 24 years rowed 10% faster than females of similar age, body height and body mass. This is most likely a result of the ability for males to generate higher force and power output10,11 and larger muscle cross-sectional area and muscle fiber size than females.12–14

Gender differences in sagittal plane lumbar spine and pelvic kinematics during rowing have also been investigated in adults. McGregor et al (2008) compared pelvic and lumbar kinematics between elite male and female rowers during ergometer rowing at varying intensities and found that females displayed greater anterior rotation of the pelvis than males. However, the authors did not investigate the thoracic spine and considered the lumbar spine as a single segment, despite growing evidence to support the importance of measuring regional differences in the lumbar spine.15–17

Gender differences in back muscle endurance performance have also been reported, with females having greater endurance.12,18,19 This might have implications for maintaining technique over time. For example, prolonged ergometer rowing has been associated with increased lumbar spine sagittal range of movement20 and increased lumbar spine flexion relative to end range.2 However, gender differences in the effect of prolonged ergometer rowing on kinematics have not yet been investigated.

Therefore, it was hypothesized that differences would exist in the pelvic, regional lumbar and lower thoracic kinematics between genders at the start and end of a prolonged ergometer rowing trial, and the aim of this study was to explore these differences. Specifically, it was
hypothesized that gender differences would be evident in (1) the maximum end range flexion determined in static sitting (slouch sitting posture), (2) the thoracic, upper lumbar, lower lumbar and pelvic kinematics during a prolonged ergometer rowing trial, and (3) stroke length and duration of drive phase in the rowing cycle.

**Methods**

Twenty healthy adolescent rowers were recruited from private high schools and domestic rowing clubs. Participants included ten males [mean and standard deviation (SD) age 17.2 (1.4) years, height 1.85 (0.07) m and mass 78.2 (12.9) kg] and ten females [age 16.8 (0.7) years, height 1.67 (0.07) m and mass 61.0 (9.4) kg]. The inclusion criteria for this study included being aged between 14 and 19 years, rowing for a club or school at least three times per week and having completed at least one full competitive season of rowing. Rowers were excluded if they reported any musculoskeletal pain in the six weeks preceding testing, had any history of LBP, or had received any form of postural training/retraining. Permission to conduct the study was granted by the Institutional Human Research Ethics Committee and all subjects and their parents/guardians (where necessary) provided written informed consent.

**Data Collection**

Participants’ pelvic, regional lower lumbar and lower thoracic kinematics were recorded using the 3-Space Fastrak system at a rate of 25 Hz (Polhemus Navigation Science Division, Kaiser Aerospace, Vermont). For this purpose, four electromagnetic sensors were secured onto the participants’ skin overlying the spinous processes of S2, L3, T12 and T6 using double-sided tape and Fixomull. The Fastrak system has been reported to be valid and reliable, reporting average errors of less than 0.2°.21

Participants first performed a “slouch” test to determine the angle equivalent to their end of range position into seated trunk flexion. This test required participants to sit on a height adjustable stool, with their thighs parallel to the floor, knees flexed 90°, their feet shoulder width apart and their arms crossed in front of the chest.15 Participants were then asked to slouch as far down as possible while maintaining the shoulders and hips vertically aligned. They were instructed to hold this position for 5 seconds. This process was repeated three times.

Participants then completed a warm-up of 5–10 minutes of submaximal ergometer rowing. The ergometer used in this study was a modified Concept II ergometer, to not interfere with Fastrak recording, as previously detailed.22 During rowing trials the source of the Fastrak device was firmly secured on a rigid wooden structure attached to the rear of the sliding seat of the ergometer.22 The Fastrak’s source was positioned so that its anterior-posterior axis was orientated as close as possible to vertical. For the purpose of determining stroke length and actual stroke rate, a rotary encoder was connected to the flywheel of the rowing ergometer. At the start of every testing session a stroke length to voltage calibration was conducted. The rotary encoder was synchronized with the Fastrak device through an AD board linked to a customized LabVIEW software program (Version 8.6.1, National Instruments, Texas, USA).

During the rowing trial, participants were requested to row at 22 strokes per minute, at a rating of perceived exertion (RPE) of 17/20 for a period of 20 minutes. The RPE was collected at the beginning of every minute during the rowing trial and at the end of the 20-minute ergometer trial. The RPE collected at the end of the ergometer trial was to ensure that exercise intensity during the rowing ergometer trial was at the intended level. RPE is considered a valid and reliable measure of exercise intensity23 and has been used in other sport-related investigations.24,25 The length and stroke rate of the rowing trial was decided upon after consultation with a group of coaches (of these athletes) who indicated 20-minute ergometer sessions were part of their normal off-water rowing training. Kinematic data were collected during the last 15 seconds of the 1st and 20th minutes. During this time, at least five complete rowing cycles were collected. The drive phase of the middle three trials was used for analysis.

**Data Analysis**

All outputs derived from the 3-Space Fastrak were converted from an azimuth, elevation and roll (ZYX) ordered sequence of rotations to a sequence of elevation, azimuth and roll via matrix algebra procedures26 using customized LabVIEW software (Version 8.6.1, National Instruments, Texas, USA). In this study, only the elevation plane was necessary to calculate the following four trunk and pelvis sagittal plane angles.15 Pelvis angle (PA)—angle of the S2 sensor relative to the vertical axis of the electromagnetic source; lower lumbar angle (LLA)—angle of the L3 sensor relative to the S2 sensor; upper lumbar angle (ULA)—angle of the T12 sensor relative to the L3 sensor and lower thoracic angle (LTA)—angle of the T6 sensor relative to the T12 sensor.

All drive phase data were time normalized (0% to 100%) using cubic spline interpolation and the length of the ergometer chain to define both the beginning of the drive (0%) and end of drive phase (100%). The drive phase during ergometer rowing is defined as the point of maximum forward reach, which is the maximum backward lean, which is where the chain length is shortest, to the maximum forward reach, which is where the chain length is longest. From this information, stroke length and the proportion of the stroke in the drive phase were also determined.

There were two distinct types of angles reported in this study, the uncorrected raw angles and slouch corrected angles. For the raw angles, 0° reflected a vertically orientated trunk position, positive values indicated flexion (anterior pelvic tilt in the case of the pelvis), while negative values indicated extension (posterior pelvic tilt in the case of the pelvis).15 For slouch corrected angles, 0°
reflected the participant’s maximum slouch sitting position, therefore positive angles represent flexing (anterior pelvic tilt) beyond the maximum slouch sitting posture and negative angles represent extension (posterior pelvic tilt) from the maximum slouch sitting posture.

The maximum PA, LLA, ULA and LTA angles were averaged over the three slouch sitting trials. For the rowing trials the maximum and minimum of each angle was extracted to calculate the range. These, along with the mean of each of the angles, were averaged across each of the three trials at both the 1st and 20th minutes.

**Statistical Analysis**

Four sets of statistical analyses were performed. Firstly, intraclass correlation coefficients (ICC3,1) were used to determine the within subject reliability of each subject’s kinematic data, percentage of cycle in the drive phase and stroke length across the three completed cycles collected at the end of the 1st and 20th minutes. Secondly, an independent t test was used to compare the angles during the slouch sitting trial between genders to determine if the PA, LLA, ULA and LTA end range flexion mobility was different between genders. This was followed by an independent linear mixed effects model to compare the average raw and slouch corrected angles (mean and range) between male and female adolescent rowers between the 1st and 20th minute. Post hoc comparisons were used to delineate the independent effect of gender and time on kinematics. Interaction between gender and time were examined, and if nonsignificant, comparisons between genders during the 1st and 20th minutes were performed using pooled data (ie, 1st and 20th minute for the gender comparison, and males and females for the time comparison). Finally, two-way ANOVA were used to compare differences between the average drive duration, stroke rate and stroke length between male and female adolescent rowers between the 1st and 20th minute. A further two-way ANOVA with covariates was used to compare stroke length adjusted for height and weight. Interaction between gender and time were also examined as stated above such that gender comparisons can be made between the 1st and 20th minutes. Confidence intervals (95% confidence intervals) for spatiotemporal kinematics were also conducted. All statistical procedures were conducted using SPSSV19.0 and the level of significance was set at \( P < .05 \).

**Results**

Intraclass correlation coefficients revealed good to excellent reliability for both spatial and temporal kinematics including stroke rate (ICC range = 0.989–0.998), PA, LLA, ULA and LTA kinematics (ICC range= 0.679–0.998) and in percentage of stroke in drive phase (ICC range = 0.935–0.977). Therefore, data for the three strokes at each time period were averaged for each participant.

No differences were found in the maximum slouch angles between genders in the PA, LLA and ULA. However, males demonstrated significantly greater LTA end range flexion when compared with females (Table 1).

The analysis of all raw and slouch corrected spatial kinematic data revealed some spatial kinematics differences between genders and over time. These results are presented in Table 2 and Figure 1. The analysis of raw PA revealed males typically postured their pelvis in more posterior tilt throughout the drive phase than females. Furthermore, rowers in both genders became more posteriorly tilted in the pelvis (9.5°) after 20 minutes of rowing. The mean LLA revealed no differences between-gender or over time in the raw angles. The analysis of the mean raw ULA revealed that there were no statistically significant differences between genders, but a significant increase in ULA flexion over time for both genders was observed (mean difference 4.0°).

The analysis of the mean raw LTA revealed that males postured their LTA significantly more flexed than females in the raw angles (mean difference 8.3°), and rowers of both genders also postured their LTA significantly more flexed in the 20th minute compared with the 1st minute (mean difference 3.5°) (Table 2 and Figure 1). The analysis of all slouch corrected angles (PA, LLA, ULA and LTA normalized to each participant’s maximum slouch position) revealed no significance difference between genders or over time.

No significant differences were found in stroke rate between genders over time, however differences were found in the drive phase duration. The results revealed no significant differences in stroke rate between genders over time (difference, 0.4 spm; 95% CI: –0.996, 1.597; \( P = .547 \)). However, the results indicated a trend for males to have greater stroke lengths over time than females (difference, 0.1 m; 95% CI: –0.17, –0.02; \( P = .056 \)), albeit not less than 0.05 m (difference, 0.05 m, 95% CI: –0.052,

<table>
<thead>
<tr>
<th>Angles</th>
<th>Males (°)</th>
<th>Females (°)</th>
<th>Differences (°)</th>
<th>P-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>–3.5° (14.9)</td>
<td>3.5° (12.7)</td>
<td>7.0°</td>
<td>.319</td>
<td>–21.4, 7.4</td>
</tr>
<tr>
<td>LLA</td>
<td>4.5° (7.9)</td>
<td>–0.1° (12.8)</td>
<td>4.6°</td>
<td>.369</td>
<td>–6.0, 15.3</td>
</tr>
<tr>
<td>ULA</td>
<td>7.4° (6.7)</td>
<td>8.6° (8.1)</td>
<td>1.2°</td>
<td>.733</td>
<td>–8.7, 6.3</td>
</tr>
<tr>
<td>LTA</td>
<td>20.1° (8.5)</td>
<td>3.7° (9.8)</td>
<td>16.4°</td>
<td>.002*</td>
<td>7.3, 25.7</td>
</tr>
</tbody>
</table>

*Denotes statistical significant differences \( (P < .05) \) between genders.
Figure 1 — Raw (left) and slouch corrected (right) angles of the PA, LLA, ULA and LTA during the drive phase of the 1st and 20th minute of a rowing stroke for males and females during ergometer trial.

Discussion

This study demonstrated significant and consistent gender differences in PA and LTA during rowing. Adolescent male athletes rowed with their pelvis significantly more posteriorly tilted than female adolescent rowers, which corroborates prior evidence in elite adult rowers where elite female rowers rowed with their pelvis in greater anterior rotation than their male counterparts. No differences were detected in the LLA and ULA were consistent with
Table 2  Gender and time comparison of trunk and pelvic kinematics during drive phase

<table>
<thead>
<tr>
<th>Angles</th>
<th>Gender</th>
<th>1st min (diff)</th>
<th>20th min (diff)</th>
<th>Gender Comparison</th>
<th>Time Comparison</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean (diff)</td>
<td>P-value</td>
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<tr>
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<td>Raw Angles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>M</td>
<td>–22.3° (17.2)</td>
<td>–32.2° (16.2)</td>
<td>7.4°</td>
<td>.041*</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>–12.7° (15.6)</td>
<td>–21.8° (17.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLA</td>
<td>M</td>
<td>3.0° (9.6)</td>
<td>1.9° (7.5)</td>
<td>2.5°</td>
<td>.330</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>–0.4° (13.2)</td>
<td>5.0° (11.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULA</td>
<td>M</td>
<td>4.5° (8.9)</td>
<td>8.9° (10.0)</td>
<td>–1.9°</td>
<td>.429</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>6.5° (9.7)</td>
<td>9.9° (10.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTA</td>
<td>M</td>
<td>16.7° (11.6)</td>
<td>19.6° (12.8)</td>
<td>–8.3°</td>
<td>.002*</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>4.7° (7.8)</td>
<td>8.8° (7.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slouch Corrected Angles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>M</td>
<td>–17.6° (17.3)</td>
<td>–20.7° (16.1)</td>
<td>2.8°</td>
<td>.557</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>–13.3° (17.8)</td>
<td>–14.9° (22.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLA</td>
<td>M</td>
<td>–1.8° (10.6)</td>
<td>–1.4° (10.2)</td>
<td>5.0°</td>
<td>.074</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.9° (12.6)</td>
<td>3.7° (13.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULA</td>
<td>M</td>
<td>–4.6° (7.3)</td>
<td>–6.2° (10.5)</td>
<td>2.1°</td>
<td>.184</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>–0.2° (7.2)</td>
<td>1.0° (10.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTA</td>
<td>M</td>
<td>0.2° (12.2)</td>
<td>8.0° (25.4)</td>
<td>1.3°</td>
<td>.792</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>2.3° (10.0)</td>
<td>1.9° (13.4)</td>
<td></td>
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</tbody>
</table>

*Denotes statistical significant differences (P < .05) between genders.
previous reports, irrespective of the fact that this study analyzed regional lumbar kinematics as compared with lumbar kinematics as a whole. The results of the LTA demonstrate that males typically rowed with their lower thorax significantly more flexed than females, consistently throughout the drive phase. The increased LTA flexion observed in males during rowing was consistent with their increased LTA flexion observed during slouch sitting (Table 1). The reduced degree of LTA flexion observed in females in slouch sitting may explain why female rowers tended to flex further beyond end of range (as defined by maximum slouch sitting) compared with males while rowing. This may represent a potential compensation for a lack of available flexion range in the LTA to allow for anterior pelvic tilt, and ULA and LTA flexion, between the adolescent rowers demonstrated greater posterior pelvic tilt. Changes in trunk and pelvic kinematics over time may be due to viscoelastic creep associated with back muscle exertion, which is an increase in elasticity of soft tissues around spinal structures as a result of repetitive spinal flexion. Previous research has also shown a change in trunk kinematics during repetitive lifting tasks. However, further evidence in rowing is required to verify the reasons for these differences between genders and over time identified.

There are several implications from the results of this study. Firstly, the differences in pelvic kinematics between adolescent males and females are consistent with those found in adults suggesting that the gender differences observed are similar across age and experience. Secondly, the finding that males typically demonstrated greater LTA flexion and posterior pelvic tilt than females may reflect different biomechanical stresses placed through the spine during ergometer rowing. Thirdly, the finding that both males and females posture their LLA and ULA beyond full range of flexion during the drive phase of rowing (although there was a trend for this pattern to be accentuated in females) is normal in pain free rowers. Future studies are required to determine whether this phenomena has implications for end range tissue tolerance and strain. Finally, the fact that the ULTA and LTA moved further into flexion with time during prolonged ergometer rowing may also have implications for tissue strain during repeated movement tasks.

We acknowledge potential study limitations. Work rate was standardized between genders using RPE in preference of mechanical power output calculated by the ergometer as RPE was more commonly used to measure work rate in this cohort of rowers and coaches. The RPE was also collected at the end of the 20-minute ergometer trial to ensure the rowers were rowing at very high exercise intensity however the authors recognize there was still potential for some variability in force produced between genders. Only drive phase kinematics were analyzed as the loaded drive phase is known to be when peak forces and moments are generated and therefore the focus of previous performance and clinical rowing research. Furthermore age range and the impact of growth spurts and puberty status could also affect results of the study. In spite of these limitations the results are in broad agreement with previous adult rowing research suggesting that patterns observed in adults are largely reflected in adolescents.

In conclusion, there are consistent gender differences in pelvis and lower thoracic kinematics between adolescent rowers with male rowers demonstrating greater posterior pelvic tilt and lower thoracic flexion. There are also kinematic changes over time, with the pelvis, upper lumbar and lower thoracic trunk kinematics moving closer to end of range flexion (posterior pelvic tilt) over time for both genders. The results of this study provide evidence that coaching techniques should take gender differences into consideration. These findings...
may have implications for coaching practices, although whether they are related to patterns of tissue strain and injury prevalent in rowers needs to be further investigated.

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