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Relative shank to thigh length is associated with different mechanisms of power production during elite male ergometer rowing

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Abstract
The effect of anthropometric differences in shank to thigh length ratio upon timing and magnitude of joint power production during the drive phase of the rowing stroke was investigated in 14 elite male rowers. Rowers were tested on the RowPerfect ergometer which was instrumented at the handle and foot stretcher to measure force generation, and a nine segment inverse dynamics model used to calculate the rower's joint and overall power production. Rowers were divided into two groups according to relative shank thigh ratio. Time to half lumbar power generation was significantly earlier in shorter shank rowers ($p = 0.028$) compared to longer shank rowers, who showed no lumbar power generation during the same period of the drive phase. Rowers with a relatively shorter shank demonstrated earlier lumbar power generation during the drive phase resulting from restricted rotation of the pelvic segment requiring increased lumbar extension in these rowers. Earlier lumbar power generation and extension did not appear to directly affect performance measures of the short shank group, and so can be attributed to a technical adaptation developed to maximise rowing performance.

Keywords: *Anthropometry, biomechanics, ergometer rowing*

Introduction

Performance in rowing is determined by the ability of the rower to maintain a high mean boat velocity, and therefore a high average mechanical power whilst maintaining sound technical skills to ensure that the power produced contributes to boat velocity (Sanderson and Martindale, 1986). Mean propulsive power output, propulsive work consistency, and stroke-to-stroke consistency and smoothness are all considered by Smith and Spinks (1995) to make significant contributions to successful rowing performance. Power output, and more specifically Peak Power, is often used as the main identification criteria of a rower's energy production and technique efficiency, as well as having been reported to be the best predictor of 2000 m ergometer rowing performance (Bourdin et al., 2004).

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Mechanical efficiency, the ratio of work done across the joints in relation to that delivered to the handle and stretcher, is vital for successful rowing. This requires the oarsperson to time precisely the flow of energy from the legs, trunk and arms to impart propulsive power to the oar and to set the body position in readiness for the subsequent stroke, whilst overcoming the inertia of the boat and the resistance of the water (Dawson et al., 1998). Precise sequential loading of the segments is essential to maximise the power producing capability of the muscles to deliver power to the oar (Baudouin and Hawkins, 2002).

Coupled with technical ability and power production, a rower's anthropometric characteristics are important determinants for success (Soper and Hume, 2004). Rowers have been shown to exhibit proportionally longer leg lengths, standing height and greater arm length–height ratio in comparison to the general population. Highly ranked rowers were shown to be significantly taller and exhibit a greater overall body mass and lean body mass, as well as having longer forearms and thigh lengths compared to lower ranked rowers (Hahn, 1990).

Barrett and Manning (2004) correlated 2000 m performance times with anthropometric variables and identified increased body mass, height, BMI, arm span, knee-floor height and hip compression angle as having the greatest relationship with rowing performance outcomes. While anthropometric variables have been shown to correlate with overall performance the effect of anthropometric differences on the coordination and timing of the rowing stroke, as well as joint power production, have not previously been quantified.

A vertical angle of the shank segment at the catch has been advocated in the coaching literature (Nolte, 2001) and therefore the shank thigh ratio may be an important factor affecting the rower's position. If a vertical shank position was adopted at the catch, then those rowers displaying a low shank to thigh ratio (STR) may suffer a shorter horizontal drive length because the seat of the rower at the catch would be positioned further from the feet than those with a high (or more equal) STR (Figure 1). Any subsequent changes in the rowing position that result from these anthropometric discrepancies may bring about changes in the sequencing, coordination and power production of the joints at or around the catch, which in turn may have a significant effect upon the performance of the rowing stroke.

The aim of the study is to measure the timing and magnitude of joint power production during the drive phase of the rowing stroke, and to investigate the effect of differences in STR. We hypothesise that there will be differences between high and low STR rowers in drive length, segment and joint angles, and consequently joint coordination and power production.

Methods

Fourteen elite male rowers (age 25.1 $\pm$ 4.5 years; height 1.98 $\pm$ 0.07 m; mass 91.3 $\pm$ 7.5 kg) provided written informed consent to participate in the study. Participants consisted of both heavyweight and lightweight rowers made up of Olympic and international representatives ($n = 10$) national, state and university competitors ($n = 4$), including four specialist scullers, six sweep oar rowers and four who trained for both sweep rowing and sculling. Training frequencies ranged from 7–11 sessions per week. Participants were split into two groups as a result of shank to thigh ratio calculations, with seven rowers exhibiting what was deemed a low STR (mean value 92.61 $\pm$ 2.2%) and seven classified as having a high STR (mean value 100.98 $\pm$ 3.4%) (Table I). The University of Sydney Human Ethics Review Committee approved this study.

Participants were tested at 32 strokes / minute on an instrumented RowPerfect rowing simulator (Care RowPerfect BV, 7772 JV Hardenberg, The Netherlands), which consists

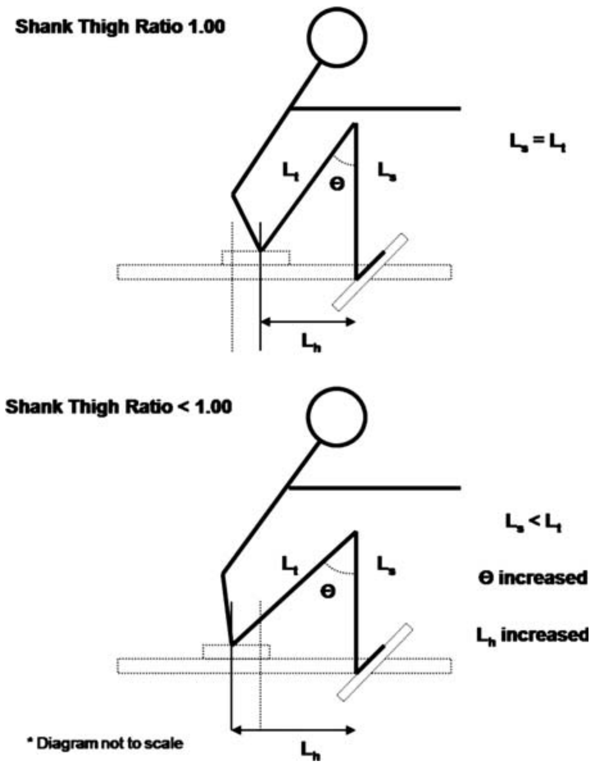

Figure 1. The effect of shank to thigh ratio on body position at the catch. These diagrams illustrate that when a vertical shank angle is adopted, a lower shank to thigh ratio should result in a more extended knee angle. For example; High STR: Shank Length = 0.55m, Thigh Length = 0.55m, Horizontal Displacement between feet and seat = 0.40m, Knee Angle at Catch = 47.7°. Low STR: Shank Length = 0.52m, Thigh Length = 0.55m, Horizontal Displacement between feet and seat = 0.43m, Knee Angle at Catch = 51.5°. (Height of Seat above feet = 0.18m). A vertical shank angle at the catch has been reported in the literature to be desired by coaches (Nolte, 2001).

Table I. Anthropometric measurements of subjects (mean ± *s*).

	Mass (kg)	Height (m)	Shank to Thigh Ratio (%)
LOW STR (n = 7)	86.0 ± 6.4*	1.88 ± 0.09	92.6 ± 2.1*
HIGH STR (n = 7)	96.6 ± 4.1	1.94 ± 0.02	100.9 ± 3.4

*Significant difference between low STR and high STR groups ($P \leq 0.05$).

of a conventional sliding seat and a stretcher–flywheel mechanism that is also free to move along the central slide bar. The air-braked flywheel is connected to the handle via a recoiling chain and the flywheel resistance was set using a 400 mm diameter wind disc, a setting commonly used by elite rowers. Subjects rowed at 32 strokes / minute and were provided with visual information feedback of stroke rate via a digital display mounted on the ergometer (Speed Coach, Nielsen-Kellerman, Marcus Hook, PA USA). Subjects were instructed to perform their usual rowing technique, especially in terms of stoke length.

All rowers had previous experience with the RowPerfect ergometer and were familiar with the test conditions. A short period (5 minutes) of familiarisation was conducted immediately prior to testing, to allow subjects to prepare for the test procedure. Participants then performed one minute of rowing at 80% of maximal propulsive power; a compromise between maximal and mid-race power (60–70% maximum, Hartmann et al., 1993). Feedback was provided for stroke rate but not power output.

Force data collection

The ergometer was instrumented to measure the external forces generated by the rower at the hands and feet. Two foot stretchers were constructed, each fitted with two force transducers (Model 9067, Kistler Instrument Corp., AG Winterthur, Switzerland, linearity $\leq$ 0.5%, hysteresis $\leq$ 0.5%) to record three-dimensional (3D) reaction forces and the centre of pressure in line with the long axis of the foot-stretcher. A unidimensional force transducer (Model TLL-500, Transducer Techniques Inc., CA, USA, linearity 0.24%, hysteresis 0.08%) was connected in series at the chain-handle attachment. The force transducers were calibrated against a force platform (Model 9281A, Kistler Instrument Corp., AG Winterthur, Switzerland) and checked prior to each session using a known weight.

Kinematic data collection

The kinematics of the rowing stroke was recorded in 3D to provide more accurate joint centre data for the saggital plane model of the rower. To record the 3D body motion, reflective markers were attached to specific anatomical landmarks on the participant encompassing 13 joints and 15 body segments. Fifty two markers (15 mm diameter) were placed for an initial static trial with 12 of these being removed for the following rowing trials (Figure 2). The static trial was necessary to define joint centres and segment coordinate systems using KinTrak software (Version 6.2, University of Calgary, Canada, 2001). The 3D trajectories of the joint centres were then calculated for each rowing trial. The shoulder joint centre was identified using the methods of Veeger (2000) and the hip joint centre using those of Bell et al. (1990). The motion of the ergometer and its handle was defined by seven reflective markers attached to the top and bottom of the foot stretcher, the chain force transducer, the handle extremities and the centre of the flywheel.

Nine video cameras provided input for the motion analysis system (Expertvision 3D, Motion Analysis Corporation, USA). Motion capture software (EVaRT 4.0, Motion Analysis Corporation, USA) enabled synchronized recording of 3D motion tracking and force analogue channels, which were sampled at 60 and 120 Hz respectively. The first five strokes ($\sim$15 seconds) were sufficient for the subject to reach the desired stable stroke rate. Kinematic and force data were recorded for the last 45 seconds of each one minute trial, to ensure the capture of 10 full strokes for analysis.

The spectra of position and force data were analysed to determine optimum cut-off frequencies for the raw data according to the method of Giakas and Baltzopoulos (1997). The outcome of this analysis was a second order Butterworth filter with a cut-off frequency of 5 Hz for position and 10 Hz for force data.

Inverse dynamics modelling

Using a two-dimensional nine-segment whole-body model, the net joint forces and moments were calculated in a custom program (Buck et al., 2000) based on the inverse dynamics method described by Winter (1990). The nine segments were linked by hinge joints, with

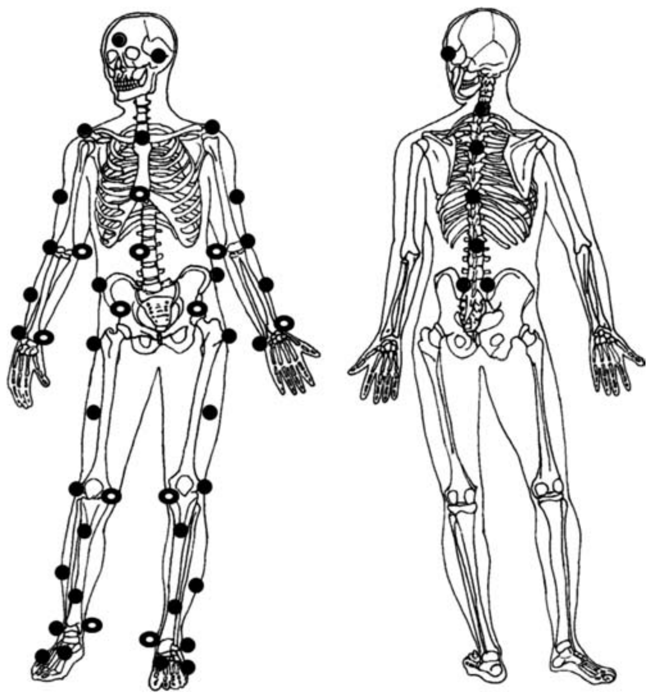

Figure 2. Anterior and posterior view of subject marker placement. The marker set up included 12 static pose markers (◉) which were removed prior to the rowing trial, and 40 dynamic markers (●) which remained intact throughout the entire testing session.

an exception being the shoulder joint where the sliding of the joint was also taken into account, resulting in 19 degrees of freedom for the model.

The average position of the joint centres and stretcher forces were calculated for the two-dimensional model. Segment masses were estimated using parameters from Kreighbaum and Barthels (1985). The position of segment centres of mass and moment of inertia properties were derived from Winter (1990) except for the trunk segment centre of mass which was from Zatsiorsky and Yakunin (1991).

The first part of the inverse dynamics analysis started from the handle force, extending through the upper limb and down the trunk to the hip joint. The trunk segment, with embedded reference frame, was defined as a rigid body running from 50 mm anterior to C7 along the spinal longitudinal axis to the L4 / L5 disc centroid. The L4 / L5 disc centroid was estimated using the iliac crests as the most lateral part of the torso at the caudal level, and mid-distance between the anterior and posterior skin surface along the iliac line as the anterior-posterior coordinate (McGill et al., 1988). The contribution of the shoulder joint force to the trunk moment was calculated by considering the location of the sliding joint centre with respect to the C7 – L4 / L5 trunk segment.

A second inverse dynamics calculation was initiated starting from the foot stretcher force extending up the lower limb to estimate the net hip moment. The root mean square (RMS) error between the two estimates of hip moment was used as a measure of the validity of the overall inverse dynamics method. The RMS error between the net hip moments of the "stretcher up" and "handle down" inverse dynamics method was calculated at RMS error 4.9 ± 4.0 N·m, less than 5% of the peak to peak amplitude of the hip joint moment.

Analysis of results

Ten full strokes were analysed from each rowing trial. These stokes were defined by the absolute handle displacement relative to ergometer position, beginning at the catch when the handle begins its negative horizontal displacement and finishing at the completion of a full cycle. Each stroke was time normalised to 100% stroke. All 10 strokes were used to form an average stroke profile for each rower, and then ensemble force-time stroke profiles were calculated to represent the mean of both low and high STR groups, with 95% confidence intervals included to indicate variability across subjects (Winter, 1984). Data were analysed only during the drive phase of the stroke, which is when power is generated by the interaction of forces between the rower and the ergometer.

Joint power production was calculated using the joint moment multiplied by the angular velocity. After integrating power over time, a half power point (the percentage time where half of the energy for the drive phase has been generated or absorbed) was computed for each joint. This method was used to enable consideration of all the power generated or absorbed across a joint during the drive phase, when some subjects demonstrated two periods of generation or absorption in a single stroke (Figure 3).

Statistical tests

Multivariate analysis of variance with repeated measures (SPSS for Windows, SPSS Inc., USA) was used to test the significance of any observed differences in the means between low and high STR groups. The degrees of freedom were adjusted (Huyn-Feldt) if the data failed Mauchly's test of sphericity. *A priori* contrasts (simple for group, polynomial for stroke) and *post hoc* pairwise comparisons were used and the 0.05 level adopted for statistical significance. A Bonferroni adjustment was made for pairwise comparisons and multiple dependent variables. Time series data were compared using 95% confidence intervals to determine the periods where curves fell within similar ranges, and when data showed differences in the phases of the curves. The 95% confidence intervals of both groups were

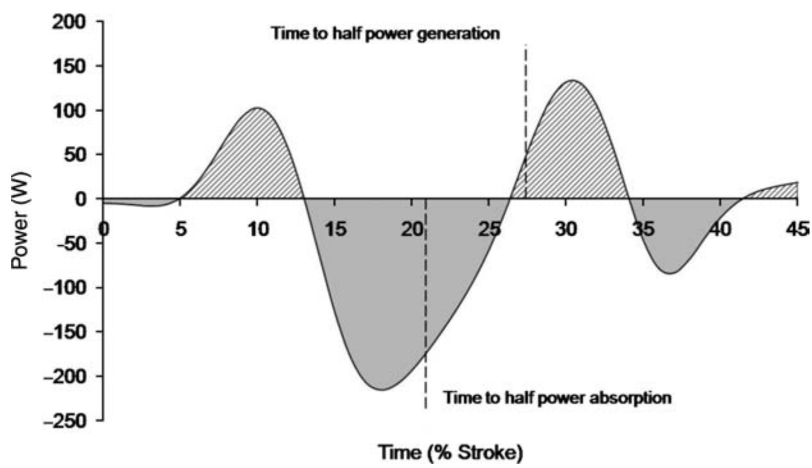

Figure 3. A power curve taken from one rower to demonstrate the time to half power calculation method. The time about which half of the power generated or absorbed by the rower during the drive phase was calculated by considering all of the power generation or absorption that occurred at a particular joint throughout the entire phase. This method was deemed necessary due to the presence of multiple periods of power generation or absorption occurring during the same drive phase.

used in the between group analysis, however the 95% confidence intervals were only displayed for the high STR group in the figures so enhance the clarity of the figures.

Results

The mean lumbar extension moment of the low STR group was greater than that of the high STR group and lay outside the 95% confidence interval during the first 5% of the stroke (Figure 4a). The mean lumbar angular velocity of the low STR group displays extension during the first 10% of the stroke, and for this period again lies outside the 95% confidence interval of the high STR group, who exhibit a mean angular velocity of almost zero during this period (Figure 4b). The mean lumbar power generation during this same 10% period of the stroke for the low STR group lies outside the 95% confidence interval of the high STR group (Figure 4c). Throughout the first 30% of the stroke, the low STR time series for both the mean angular velocity and power are out of phase with those of the high STR group. The magnitude of peak lumbar power absorption was not found to be significantly different between the two groups ($p = 0.285$). This was a result of substantial variance in the power outputs of the low STR group, which meant that the mean power absorption of the high STR group was within the 95% confidence intervals of the low STR group (mean value $-$ 801.54 $\pm$ 680.61 W).

Joint segment angles were calculated as the angle of each segment from the right hand horizontal of its distal joint centre. The mean trunk angle shows continual and comparable extension in both groups throughout the drive phase (Figure 5a) although the low STR group does display a slightly more flexed position at the catch, and lies outside of the 95% confidence intervals of the high STR group throughout the first 25% of the stroke. The mean pelvic angle of the low STR group shows little change over the early portion of the drive phase, after which it begins to rotate posteriorly (Figure 5b). The pelvic angle of the high STR group shows gradual posterior rotation from the catch resulting in the mean of the low STR group being outside of the 95% confidence interval of the high STR group between approximately 5–20% of the drive phase. The lumbar angle was calculated from the difference between the trunk and pelvic segments. The mean lumbar angle shows early extension in the low STR group, while the high STR group showed no such extension (Figure 5c). The mean of the low STR group lies outside of the 95% confidence interval of the high STR group between 10 and 20% of the drive phase and again after 25%, as the low STR group change from being initially more extended to finishing the stroke in a more flexed position.

The time to half lumbar power generation was significantly earlier for the low STR group when compared to the high STR rowers ($p = 0.028$, Table II). Timing differences were obtained independent of other anthropometric variables such as height and weight of the respective groups. These variables were included during preliminary statistical analyses as independent variables however there were no apparent timing differences between groupings based on these other variables. There were no significant differences for time to power absorption or generation at either the knee, hip or shoulder joints between the low and high STR groups (Table II).

Rowers with a low STR had a greater mean hip extension moment at the catch when compared to the high STR group, which decreased immediately after the catch over the first 5% of the stroke (Figure 6a). The extension moment then lay within the 95% confidence interval of the high STR group, with both groups moving largely in phase throughout the rest of the drive period. Mean hip angular velocity (Figure 6b) was similar at the catch for both groups. The low STR group, however, lay just outside of the 95% confidence intervals of the high STR group between 2–10% of the stroke with a reduced angular velocity, and between

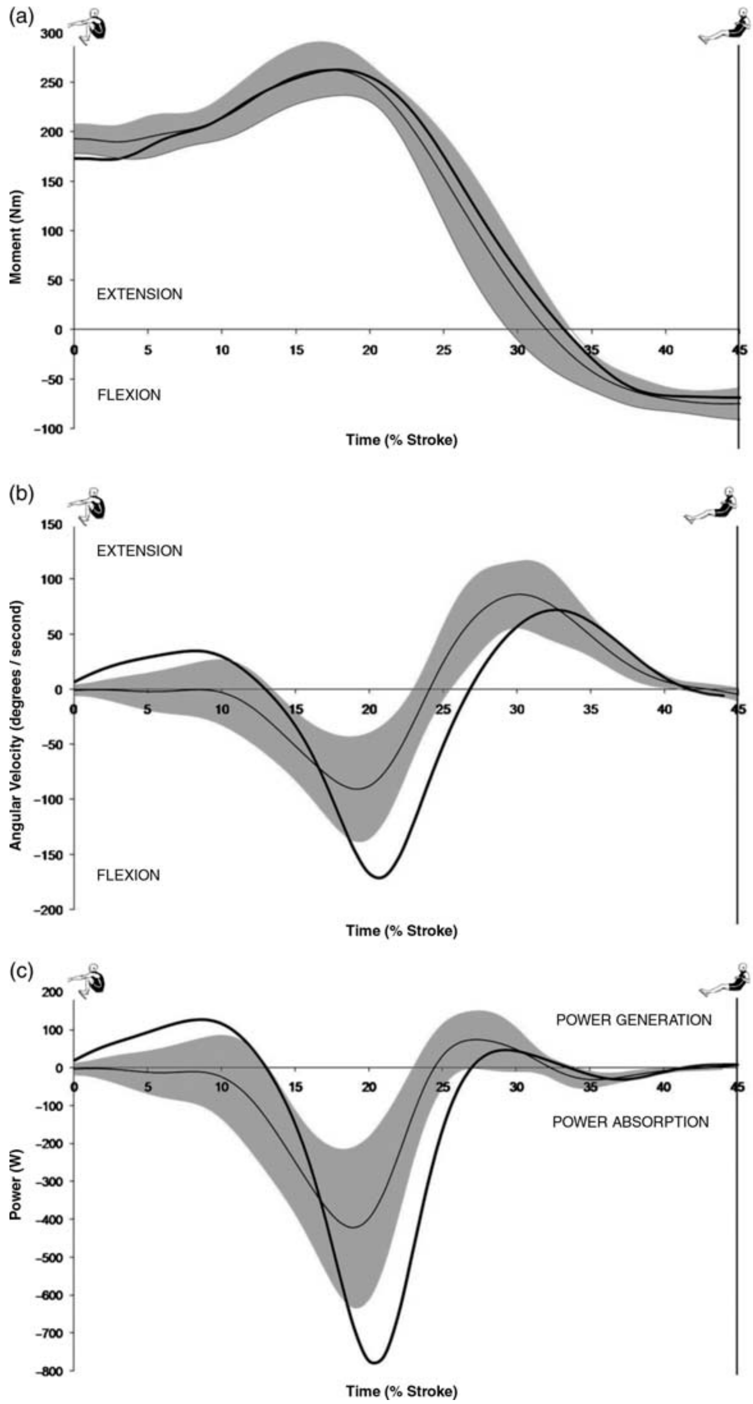

Figure 4. Lumbar joint moment, angular velocity and power during the drive phase. The figures depict normalised stroke profiles of ensemble means for joint moment (a), angular velocity (b) and power production (c). The shaded area illustrates the 95% confidence interval for the High STR group. The 95% confidence intervals are shown only for the High STR group to improve clarity of the figures. Rowing figures depict the catch and finish positions.

20–25% of the stroke due to a delayed and increased angular velocity. The mean hip power curve followed the same trait as the angular velocity curve, with the low STR group again lying outside of the 95% confidence intervals of the high STR group at 2–10% (power reduced) and 20–25% of the stroke (power increased and delayed).

The timing and magnitude of overall peak power output, incorporating both the handle and the foot stretcher forces (Figure 7), showed no significant difference between groups ($p = 0.508$). The peak power output at the major power producing joints (knee, hip, shoulder, lumbar) was analysed for all rowers, and showed no significant findings between the two groups for timing or magnitude of peak joint power production ($p > 0.05$).

The mean angles of the shank and the thigh segments showed no significant difference between groups at either the catch or the finish position, despite the significant difference in the ratio of shank to thigh length (Table III). Both groups also exhibited comparable ranges of joint movement at both the knee and hip.

Drive times showed no difference between groups ($p = 0.337$), with low and high STR groups recording drive times averaging 44.6 ± 1.3% and 43.8 ± 1.9% respectively of the total stroke time. The drive length also showed no differences ($p = 0.416$) with mean values of 1.50 ± 0.07 m and 1.53 ± 0.08 m recorded for the low and high STR groups respectively.

Discussion and implications

Earlier lumbar power generation was exhibited in rowers with a low STR (Table II, Figure 4c), when force was applied to the handle soon after the catch. It can be seen that earlier lumbar power generation occurring in the low STR rowers was a result of the rowers actively extending their lumbar spine throughout the early portion of the drive phase (Figure 4b). In the high STR group, there was little or no angular velocity in the lumbar region, resulting in no power being generated by the lumbar region during the early portion of the drive phase (Figure 4c).

Nolte (1991) reported that flexion of the lumbar region at the catch is advocated by coaches as it is thought to increase length of the stroke in the early drive phase. However, after the catch, the lumbar region should act to transfer the power created by the leg drive to the handle via a braced and stationary trunk–pelvis (lumbar) angle (Mazzone, 1988; Nolte, 1991; 2001).

While the lumbar angle at the catch was similar for both groups, our findings differ from those recommended in the coaching literature due to active lumbar extension seen in the low STR group after the catch (Figure 5), which coincides with the period of lumbar power generation. The absence of lumbar extension, and subsequent lumbar power generation, in the high STR group suggests that their lumbar region is braced and isometric as recommended in the literature.

Rotation of the pelvic segment appears to be restricted in the low STR group during early portion of the drive phase, which requires the lumbar region to undergo extension in the early drive phase (Figure 5b). The pelvic orientation of both groups was similar at the catch, with rotation of the pelvis about the hip joint coordinated with trunk extension in the high STR group resulting in a constant lumbar angle. The restricted rotation of the pelvic segment in the low STR group, however, meant that the continuous extension of the trunk required active extension of the lumbar region. At the time of peak lumbar power generation (8–10% of stroke), the mean pelvic angle of the low STR group remained relatively stationary, and lay outside the 95% confidence intervals of the high STR group.

Restricted rotation of the pelvis during the early drive phase is comparable to reports by Bull and McGregor (2000), who reported that pelvic rotation was delayed in rowers

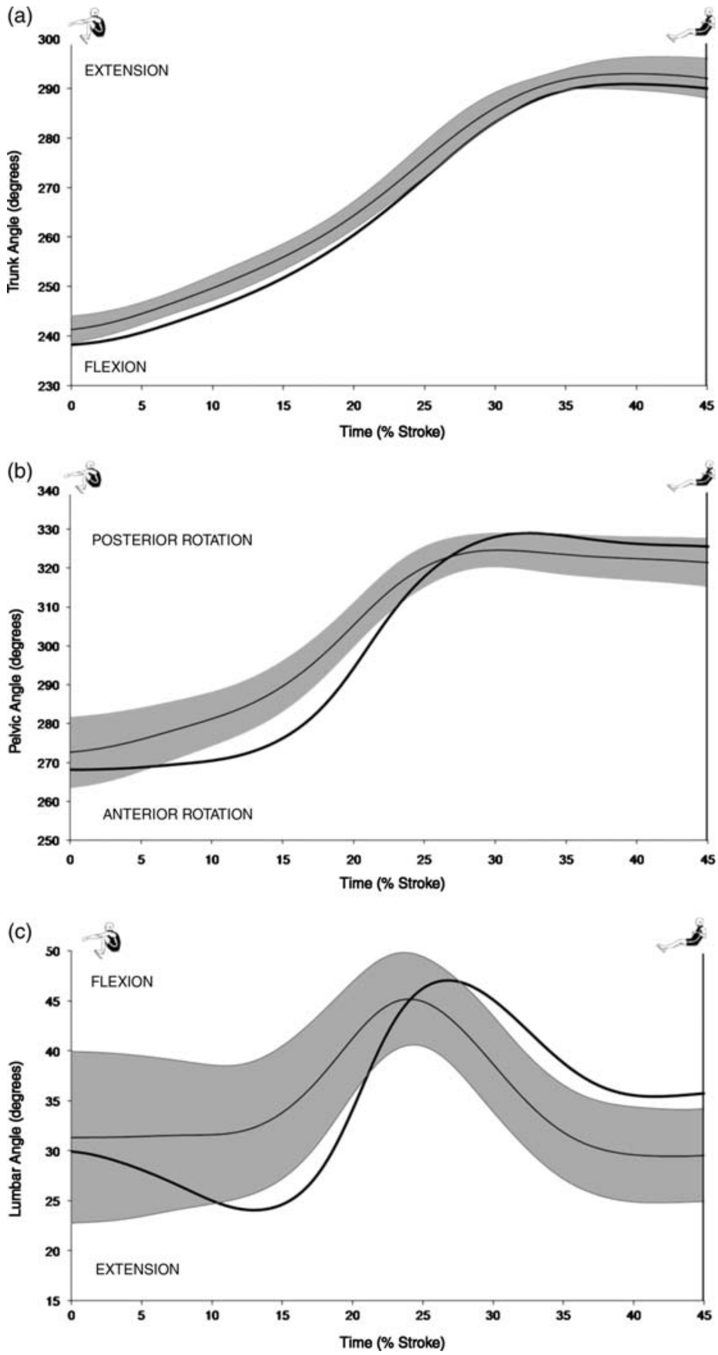

Figure 5. Trunk, pelvis and lumbar joint angles during the drive phase. The figures depict the normalised stroke profiles of ensemble means for trunk angle (a), pelvic angle (b) and lumbar angle (c). The shaded area illustrates the 95% confidence interval for the High STR group. The 95% confidence intervals are shown only for the High STR group to improve clarity of the figures. Rowing figures depict the catch and finish positions.

exhibiting what was described as the "bum shoving" technique, in which the legs are extended first during the drive phase with the torso and arms then being drawn into the stroke as a result. Rowers in the present study, however, showed no evidence of this technique as the restricted pelvic rotation was supplemented by an active extension of the lumbar spine. While the "bum shoving" technique increases the role and dependence on the lower extremity early in the drive phase, the low STR rowers of the present study used an increased and earlier role of the lumbar region to maintain a continuous sequence of power delivery to the handle.

Active extension of the lumbar region, resulting in lumbar power generation, appears to be necessary in the low STR group as the result of reduced power production at the hip joint when compared to the high STR group (Figure 6c). Rowers in the low STR group had a reduced hip extensor velocity (Figure 6b) in the early stages of the drive phase, which lay outside of the 95% confidence intervals of the high STR group, and subsequently resulted in a reduced power generation at the hip joint.

Reduced power production during the early stages of the drive phase at the hip joint may necessitate the earlier power generation at the lumbar region in order to maintain power delivery to the ergometer. The power delivered to the ergometer (Figure 7) supports this hypothesis, as there were no differences in the timing or magnitude of power delivery to the ergometer between the STR groups.

Power delivery to the handle is considered to be one of the major determinants of successful rowing performance (Smith and Spinks, 1995), and continuous and smooth handle power delivery from the catch onwards has been regularly referred to in the coaching literature as essential to maximise boat speed (Dal Monte and Komor, 1989; Tonks, 2005). This may lead us to suggest that in order to apply pressure at the handle, and then continually deliver power throughout the drive phase with the same timing and magnitude as the high STR rowers, the low STR rowers have had to adapt their technique and power production sequence accordingly. It may be that through training or coaching, the low STR rowers have developed a strategy which demands earlier lumbar power generation after the catch to counteract their reduced hip power production, enabling these rowers to deliver the same power to the ergometer.

In an attempt to coordinate the timing and magnitude of power delivery to the handle, the rowers change the time about which power is generated across the lumbar joint. Earlier timing of these generation moments by the low STR group may potentially predispose those muscles involved in lumbar extension, and the spinal structures to which they are attached, to greater stresses. These may result from higher lumbar loading and power generation occurring early in the drive phase while the movement velocity is low. This is in contrast to the braced lumbar region exhibited early in the drive phase by the high STR group, with their lumbar power generation occurring later in the phase as the segment velocities increase and the peak segmental forces decrease (Baudouin and Hawkins, 2002).

It must be noted that although the low STR group as a whole showed earlier and increased lumbar power generation, individual differences did exist within the group in terms of both the timing and magnitude of lumbar generation, with some rowers exhibiting similar lumbar activity to those with a high STR. Therefore, it may appear that the proposed strategy developed by the low STR group to enable maintenance of power delivery may be less relevant to some rowers within the low STR cohort than others. Possible reasons for this need to be further examined in future studies, but may provide important insights into how to reduce potential problems which may arise in rowers with these anthropometric discrepancies.

Table II. Timing of joint power generation and power absorption at the four major joints contributing during the drive phase. The mid point (or time) about which the majority of either power generation or absorption at a particular joint occurred was taken to represent the time of half power production or absorption (mean ± *s*).

	Knee generation (% Stroke)	Knee absorption (% Stroke)	Hip generation (% Stroke)	Lumbar generation (% Stroke)	Lumbar absorption (% Stroke)	Shoulder generation (% Stroke)	Shoulder absorption (% Stroke)
LOW STR	13.52 ± 2.74	32.25 ± 7.62	19.21 ± 1.45	12.70 ± 6.61*	20.70 ± 1.17	22.34 ± 1.57	40.92 ± 0.92
HIGH STR	13.44 ± 2.41	27.38 ± 3.58	18.35 ± 2.04	22.17 ± 7.58	20.03 ± 5.22	22.62 ± 2.42	40.24 ± 2.47

*Significant difference between low STR and high STR groups ($P \leq 0.05$). No power absorption occurred at the hip joint in any subjects.

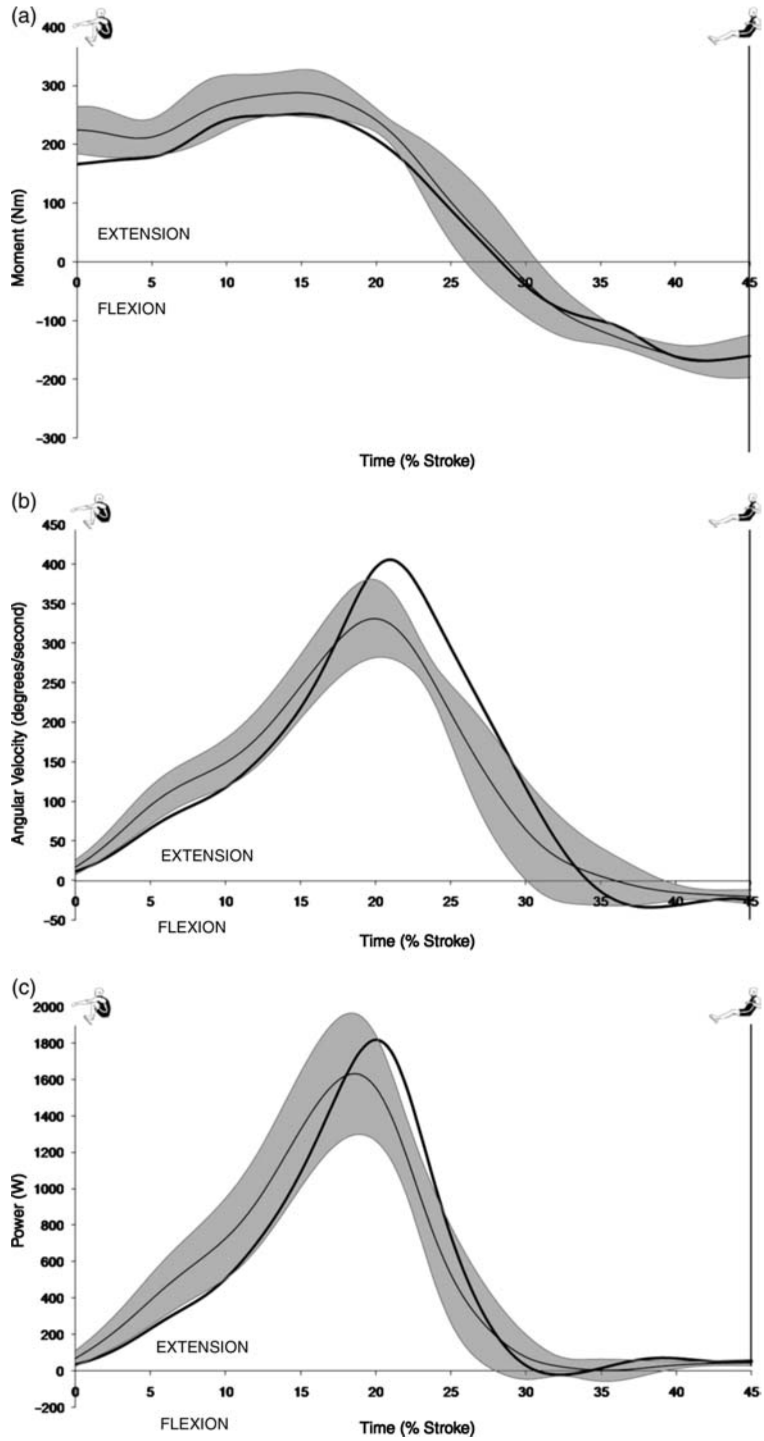

Figure 6. Hip joint moment, angular velocity and power during the drive phase. The figures depict the normalised stroke profiles of ensemble means for joint moment (a), angular velocity (b) and power production (c). The shaded area illustrates the 95% confidence interval for the High STR group. The 95% confidence intervals are shown only for the High STR group to improve clarity of the figures. Rowing figures depict the catch and finish positions.

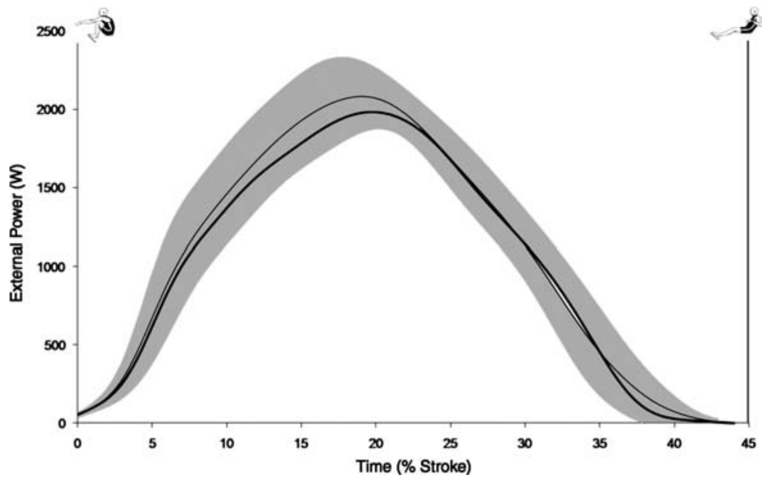

Figure 7. External power output during the drive phase. The figure depicts the normalised stroke profile of ensemble means for power output, calculated as the sum of handle power and foot stretcher power. The shaded area illustrates the 95% confidence interval for the High STR group. The 95% confidence intervals are shown only for the High STR group to improve clarity of the figures. Rowing figures depict the catch and finish position.

It was initially hypothesised that the low STR rowers, when compared to the high STR group, would display differences in their rowing position at the catch (Figure 1). It was anticipated that a longer thigh length would require the seat to be further from the feet at the catch. If this were the case, rowers with a proportionally longer thigh segment (low STR) would have to gain length at or around the catch in order to maintain the same point of force application and length of drive phase compared to those with a high STR. The lumbar angle was comparable for both groups at the catch, as were the ranges of lower limb joint motion, segment angles and drive length, irrespective of STR. Therefore, our findings do not support this hypothesis despite the continued extension after the catch in the low STR group. This suggests that this group, as a result of their longer thigh segments, have to change the time about which power is developed at the lumbar region in order to apply force to the handle.

Lack of significant differences in the kinematic results may be explained to some extent by the relatively small group sizes, leading to the data being influenced by individual differences. If rowers were to have adapted individual strategies by which they were able to increase or reduce their thigh angle at the catch to suit their individual style, then differences between groups may be masked by the effect of those factors on the overall group mean.

It has previously been reported that faster rowers display less hip flexion at the catch which enables the hip muscles to work over a more effective range of the torque–angle relationship (Barrett and Manning, 2004). Therefore the angle obtained by the rowers at the catch may not be their maximal compressed position down the slide, but an optimal hip / thigh angle over which the force generating capacity of the muscles work best. This may provide another rationale for the similar kinematic results obtained for both groups.

Further examination of the effects that these anthropometric discrepancies may have upon longer duration, race specific performance is vital to understand the role that earlier lumbar generation and reduced hip power generation may play in the efficiency of the stroke. Subsequent effects of power generation changes upon the rowing technique and performance may provide an insight into specific lumbar training programs or technical interventions which may need to be implemented within a particular rowing cohort.

Table III. Ensemble means for joint range and segment angles (mean ± *s*).

	Shank angle at catch (°)	Shank angle at finish (°)	Thigh angle at catch (°)	Thigh angle at finish (°)	Knee range of motion (°)	Hip range of motion (°)
LOW STR	87.01 ± 4.50	168.52 ± 2.82	217.64 ± 3.94	164.04 ± 4.67	135.69 ± 7.86	114.88 ± 23.66
HIGH STR	88.35 ± 3.98	168.71 ± 2.69	220.26 ± 3.28	164.92 ± 3.46	136.18 ± 6.78	107.83 ± 8.37

*Significant difference between low STR and high STR groups ($P \leq 0.05$).

This being said, this study has shown that individual rower anthropometry affects the way power is generated and absorbed at the major joints of the body. Coaches must take this into account when devising training technique, particularly in the early stages of a rower's career when motor patterns are being established. Where lumbar spine stress is involved, it would be important to apply the findings to all rowers as a preventive measure to avoid low back injury.

Differences were not revealed in the kinematic data but rather through inverse dynamics analysis. Therefore conclusions formed from kinematics data alone should be interpreted carefully. This is an important consideration for coaches too, who observe kinematics rather than kinetics.

Conclusion

Rowers with a low shank to thigh ratio demonstrate power generation at the lumbar region earlier in the drive phase, as the result of an earlier lumbar extensor velocity. This change in timing of the power generation does not, however, affect the overall timing of power delivery to the rowing ergometer.

Earlier lumbar power generation during the drive phase appears to result from restricted rotation of the pelvic segment in the low shank to thigh ratio group, which leads to increased lumbar extension during this period of the stroke in response to a reduced generation of power at the hip joint.

Whatever the mechanism of the earlier lumbar power generation and extension during the drive phase, its presence in the low shank to thigh ratio rowers does not appear to directly affect external power delivery of the rowers, and so its presence can be attributed to a technical adaptation which has been developed in order to maximise their rowing performance.

Early power generation occurring in the lumbar region does, however, raise questions as to the effect that this may have upon performance over extended race conditions. The potential exposure of low shank to thigh ratio rowers to greater stresses in both the lumbar extension muscles and the spinal structures to which they are attached may predispose these rowers to overuse injuries at a later date.

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