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Research article

THE IMPACT OF ERGOMETER DESIGN ON HIP AND TRUNK MUSCLE ACTIVITY PATTERNS IN ELITE ROWERS: AN ELECTROMYOGRAPHIC ASSESSMENT

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ABSTRACT
This study used surface electromyography (sEMG) to examine whether there were differences in hip and trunk muscle activation during the rowing cycle on two of the most widely used air braked ergometers: the Concept 2C and the Rowperfect. sEMG methods were used to record the muscle activity patterns from the right: m. Erector spinae (ES), m. Rectus Abdominus (RA), m. Rectus Femoris (RF) and m. Biceps Femoris (BF) for their contributions as agonist-antagonist pairs underlying hip and trunk extension/flexion. The sEMG activity patterns of these muscles were examined in six young male elite rowers completing a 2 minute set at a moderate training intensity (23 stroke·min^{-1} and 1:47.500 m^{-1} split time, 300W). The rowers closely maintained the required target pace through visual inspection of the standard LCD display of each ergometer. The measurements of duration of each rowing cycle and onset of each stroke during the test were recorded simultaneously with the sEMG activity through the additional instrumentation of a foot-pressure switch and handle accelerometry. There were no significant differences between the two ergometer designs in group means for: work rate (i.e., rowing speed and stroke rate), metabolic load as measured by mean heart rate, rowing cycle duration, or timing of the stroke in the cycle. 2-D motion analysis of hip and knee motion for the rowing cycle from the video footage taken during the test also revealed no significant differences in the joint range of motion between the ergometers. Ensemble average sEMG activity profiles based on 30+ strokes were obtained for each participant and normalised per 10% intervals of the cycle duration as well as for peak mean sEMG amplitude for each muscle. A repeated measures ANOVA on the sEMG activity per 10% interval for the four muscles contributing to hip and trunk motion during the rowing cycle revealed no significant differences between the Concept 2C and Rowperfect ($F = 0.070$, df = 1,5, $p = 0.802$). The outcome of this study suggests that the two different ergometer designs are equally useful for dry land training.

KEY WORDS: Flexion, extension, land-based training

INTRODUCTION

Stationary air-braked ergometers are used extensively in the sport of rowing for land-based training. To date, rowing ergometers have been extremely useful in the biomechanical analysis of rowing (Torres-Morreno et al., 2000; Smith and Loschner, 2002). Given the high reliability in measuring rowing performance and the ability to match the physiological demands of on-the-water rowing, air-braked ergometers will no doubt continue to be useful in squad selection (Lamb, 1989; MacFarlane et al., 1997; Shephard, 1998; Mahony et al., 1999). However, one criticism of the standard air-braked ergometer design has been its poor simulation of the technical aspects of rowing on the water. The most popular ergometer of U.K. rowing clubs is the Concept 2C (Concept UK). The

Concept 2C uses a fixed air-braked fly-wheel design as the power-head. During the rowing cycle, the rower slides back and forth along the monorail through the action of cyclical extension and flexion of the lower limbs. The movement generated on the fixed power-head design has been criticised for poorly simulating the movement of the boat underneath the rower and therefore hindering the development of proper rowing technique (Rekers, 1993). In contrast, another popular ergometer design, the Rowperfect (Care Rowperfect BC, JV Hardenberg, The Netherlands) incorporates a floating power-head design. The Rowperfect's innovation is that both the power-head as well as the rower's body move away from each other with little or no horizontal displacement of the rower along the monorail. The floating power-head ergometer when used correctly produces only a small amount of horizontal displacement of the rower and therefore produces a more realistic simulation of on-water rowing (Elliot et al., 2002).

A recent CODA-based motion analysis study of the floating power-head design highlighted differences in the stroke dynamics during the rowing cycle between the fixed and floating power-head ergometer configurations; both of which are possible on the Rowperfect (Bernstein et al., 2002). This study showed that total work, power per stroke, and metabolic load were not significantly different overall, but stroke length and force per stroke were greater on the fixed power-head configuration. In addition, during 20 minutes of fatiguing exercise, the stroke length on the fixed power-head changed progressively, whereas it remained constant for the floating power-head configuration. These differences, as well as the changes in technical aspects of the rowing cycle, during prolonged effort have been highlighted to have safety implications for rowers who use high-volume ergometer training (Bernstein et al., 2002). There is growing concern about the prevalence of back pain in elite rowers, and the possibility that high volume ergometer training may be a common cause of this injury. Therefore, Bernstein et al., (2002) on the basis of their biomechanical study suggested that rowers may be working harder when training on ergometers such as the Concept 2C which uses a fixed power-head.

Fatigue-induced changes in muscle activity involved in stabilising the lumbar spine and the repetitive loading of the flexed spine are cited as factors contributing to low back pain in rowers (Reid and McNair, 2000). During the rowing cycle, the movement of the trunk during extension is reported to produce compression loads on the spine as high as seven times body mass (Hosea et al., 1987). Several studies to date have looked at fatigue-induced changes in motion during prolonged bouts of training (1hr), changes in the electromyographic (EMG) activity of m. Erector Spinae (Holt et al., 2003) as well as asymmetries in back muscle in rowers (Parkin et al., 2001) in order to examine underlying factors of rowing-induced back pain. Surface electromyography of trunk extensors has also identified changes in the median frequency of the parapsinal muscles in rowers identified with back pain (Roy et al., 1991). Another study using magnetic resonance imaging has demonstrated that rowers with back pain exhibit hypomobility in lumbar flexion during rowing (McGregor et al., 2002).

However, there have been few recent studies analysing the muscle activity pattern during the rowing cycle except for earlier studies identifying general patterns of activation (Rodriquez et al., 1990; Clarys and Cabri, 1993; Wilson et al., 1998; Janshen et al., 2003). The pattern of muscle activation during repetition of the rowing cycle means that many strokes can be averaged to produce an ensemble profile of muscle activity. Similar to the type of analysis used in locomotion, the use of electromyography could be useful in comparing land-based training with on the water training, in addition to providing an assessment of the degree of muscle activation arising from possible differences in rowing ergometer designs.

In order to validate this preliminary electromyographic assessment of ergometer design, it is necessary to combine biomechanical and physiological methods for the assessment of similarity of rowing parameters in experienced rowers. We therefore combined two-dimensional (2-D) motion analysis of hip and trunk movement as well as monitoring heart rates with our electromyographic assessment during this study. Surface electromyography (sEMG) was therefore used in this study to compare, under closely matched rowing pace, the muscle activity patterns in hip and trunk muscle of elite rowers to determine whether differences in muscle activity could be detected during brief training bouts on the two prevalent air-braked ergometer designs: the Concept 2C (fixed power-head) and Rowperfect (floating power-head).

METHODS

Study design

The within participants, crossover design was used to make direct comparisons of sEMG activity patterns between the two ergometers. This study design eliminated many of the well-known problems associated with comparing sEMG activity recorded from participants in different trial sessions.

Participants
Six male rowers volunteered for the study from the University of London Boatclub. The participants consisted of 4 stroke and 2 bow oarsmen with at least 5 years rowing experience and in training for under 23s and world championship trials. The group had a mean age 19.6 ± 0.82 years, mean height 185.8 ± 6.2 cm and mean mass of 84.3 ±8.1 kg. The subjects were healthy and free of back pain injury. All participants had trained regularly on both the Concept 2C and Rowperfect ergometers. Ethical approval was obtained from the Brunel University Dept of Sport Sciences ethics review board and participants gave their written consent.

Equipment and methods
The study was undertaken at the University of London boathouse facility (Chiswick, London, UK) during the training season. All participants used the same two calibrated ergometers. All subjects performed three moderate, self-paced 2 to 3 minute rowing sets after a brief warm-up. The targeted power output for the three rowing paces were: 1st) 225 W [split time of 1:55 (Min:sec).500m^{-1}], 2nd) 250 W (1:51.500m^{-1}) and 3rd) 300 W (1:47.500m^{-1}) with the relatively low stroke rates of 20, 22 and 24 min^{-1}, respectively. The 300W set, representing a training level, was the actual test and was used for subsequent analysis. All of the rowers maintained the average target pace to within ±2 second split times of the target pace. The average work rate for the test was recorded from the ergometer's own instrumentation (LCD display) at the end of each bout. The first three sets were completed on a fixed-head ergometer (Concept 2 model C, Concept UK LTD) and then the same three sets were performed on the floating-head ergometer (Care Rowperfect BC, JV Hardenberg, The Netherlands). We did not use a randomization of the tests, but each rower rested for 1-2 minutes between each set and at least 15 minutes in between rowing on the two ergometers. The heart rates of the subjects were monitored using a heart rate monitor (Polar Edge, Polar Electro Oy, Kempele Finland) to determine metabolic load for the average work rate achieved.

A video camera (Panasonic, 50 Hz) positioned orthogonally 5 metres away from the participants was used to record the rowing sets for 2-D video motion analysis. Selected sequences of the fastest pace of a complete rowing cycle (including 5 frames before and after onset and finish) for all subjects were digitized (sampling rate of 50 Hz) using Peak Motus software (version 7, Peak Performance technologies, Colorado, USA). Eight points on the rower's right side were used to define: hip, knee, ankle and elbow joints and digitised for each frame to determine the joint angle excursions during the rowing cycle. The data were smoothed using a Butterworth filter with cut-off frequency of 6Hz. Differences in the joint angle excursions of the hip and knee were compared between the two designs.

The technical aspects of rowing were assessed from the videos of each rower on the two designs by one of the authors (RB), an experienced rower and coach. A scoring system was used ranging from 1 (poor) to 5 (excellent) for thirteen technical aspects of rowing (including: degree of back extension, sequencing of body movements, fluidity, etc) to produce average scores of the rowers on each design.

Synchronisation of sEMG data with rowing cycle
In order to synchronize the sEMG data to the rowing cycle, a record of the onset of each rowing cycle was produced. We found that the use of a pressure switch positioned on the footrest, under the upper part of the rower's foot, was reliably activated at the start of each rowing cycle. The voltage transients of the pressure switch (MT8, MIE Medical Research, Leeds UK) were recorded simultaneously with sEMG signals and were used to measure the start and end of the drive and recovery phases of the rowing cycle. The duration of the rowing cycle could be measured from consecutive foot switch events, and the duration of the drive phase measured from its onset to offset. In addition, an accelerometer was positioned on the dorsum of the hand (BIOPAC systems, triaxial accelerometer, TSD109F, Linton Instruments, Norfolk UK) to record the peak horizontal acceleration of the pull exerted on the handle. The latency to peak of the x-axis voltage trace of the accelerometer was used to determine the timing of the stroke during the rowing cycle.

EMG recordings
The use of the rowing ergometer involves bilateral activation of the muscles, therefore we recorded only from the one side (right) of the body. Differential surface electromyographic (sEMG) recordings were obtained by using pairs of circular self-adhesive surface electrodes (28mm, Arbo, Henleys Medical, Stevenage UK) placed over the muscles of the hip and trunk. Surface electrode pairs were placed using standard anatomical references (Cram and Kasman 1998) with inter-electrode distance of 2 cm to minimise cross talk from adjacent muscles. The electrode pairs were placed over: m. rectus femoris (RF) for hip flexion, m. biceps femoris (BF) for hip extension; and 2cm from midline at the L3 level for m. erector spinae (ES) as trunk extensor, and 2-3cm from midline at umbilical level for m. rectus abdominis for trunk flexion. RF and BF are bi-articular muscles active in both knee and hip extension and are active during the rowing

cycle. Although deeper muscles undoubtedly generate much of the movement of the hip and trunk during rowing, EMG recordings of these muscles would have required the use of needle electrodes, which was not deemed practical for this study. Once low noise recordings were established, all electrodes were securely fastened with medical adhesive tape to ensure that they did not move during the testing session. sEMG was recorded using signal conditioners (CED 1901 Quad system, Cambridge, UK), amplified (1000 gain); filtered (2^{nd} order Butterworth 12db/octave; 20Hz to 2kHz) then digitized (2kHz sampling rate) and stored simultaneously with the foot pressure switch and accelerometer recordings on a PC for off-line analysis (Spike for Windows, CED, Cambridge, UK). The quantification of the sEMG signals was by standard means using both the root mean square (rms) amplitude smoothing procedure (25ms time constant) and integrated area of sEMG over the rowing cycle.

Analysis

Data reduction of rowing cycle

An ensemble average of 30+ consecutive rowing strokes obtained from each rower of the fastest ($1:47 min.500m^{-1}$) pace was produced by event trigger averaging of the rowing cycle for ± 3-4 seconds around the onset of each cycle. Using a peak detect function of the footswitch records, we converted these to events for the accurate identification of the start of each cycle. Preliminary analysis of the footswitch records for each bout allowed us to reject the occasional sporadic stroke which overall, represented less than 10% of the total strokes analysed. Using this method, we produced an overall average rowing cycle profile for each rower on the two ergometer designs. We have adopted this averaging technique for profiling sEMG activity patterns from gait cycle analysis (Burden et al., 2003). Our attempts at normalizing the dynamic sEMG activity to a standard isometric maximal voluntary contraction (MVC) in each muscle, were not successful, and the problems identified with this method have been examined in gait analysis. For most of the rowers, more peak muscle sEMG activity was produced during rowing than in a manoeuvre used to produce isolated MVCs. The ensemble average sEMG profiles of the activity were therefore normalised according to the peak dynamic method described for gait analysis and evaluated in the Burden et al. paper (2003). For each rower, the time of the rowing cycle was re-expressed as a percent (%) of the total cycle duration. We normalized the mean rms sEMG amplitude for each muscle for each 10% interval of the rowing cycle to the mean peak value observed in one of the 10 intervals of the cycle. This normalization procedure of muscle activity was carried out on the EMG data obtained on each ergometer.

Statistical analysis

All statistical analyses were carried out using SPSS (Statistical Package for the Social Sciences (SPSS) version 11.5 for Windows, Chicago, Illinois, USA). Univariate tests of each relevant measure were performed using a MANOVA analysis. The tests for the effect of ergometer design were based on linearly independent pairwise comparisons based on the estimated marginal means of each variable between the two ergometer designs. The measures included: 2-D video analysis of hip and knee joint angle excursion, heart rate, rowing cycle parameters (i.e., stroke rate, cycle duration), accelerometry data, integrated sEMG per rowing cycle for each muscle and rowing technical scores. To compare the activity patterns over the rowing cycle, we employed a 3- way repeated measures ANOVA of the impact of ergometer design on magnitude differences in sEMG measures of muscle activation over each decade of rowing cycle. The analysis consisted of examining the normalized mean rms amplitudes in a 2 x 4 x 10 factor design: [2 (type of ergometer) by 4 (muscles) by 10 (10% interval of the rowing cycle)]. The means and standard deviations of the data of all measures are reported for the two ergometers. Pair-wise comparisons (using Bonferroni correction) between the two ergometers based on the estimated marginal means, were determined by SPSS. The F values of the univariate tests and the repeated measures ANOVA (Greenhouse-Geisser Correction), degrees of freedom (df), exact p values and effect sizes expressed as partial eta squared (η_p^2) are reported. Statistical significance was set at $p < 0.05$.

RESULTS

2-D video analysis of selected rowing sequences from each of the two ergometers helped identify the action of the muscles during the rowing cycle. The rowing cycle begins with ankle plantar flexion, and knee extension. Together, the coordinated action of the lower limbs generates the main body movements during the drive phase. The extension of the hip and trunk also occurs during this time. Shortly after the initiation of the drive phase, the rower pulls on the handle and the attached chain spins the air-braked flywheel in the power-head. The pulling motion of the handle simulates the stroke of the oar. At the end of the drive phase (finish) the knees are fully extended with back extension at about 100 degrees. Good technique requires an upright back posture without over-extension, and the handle pulled close

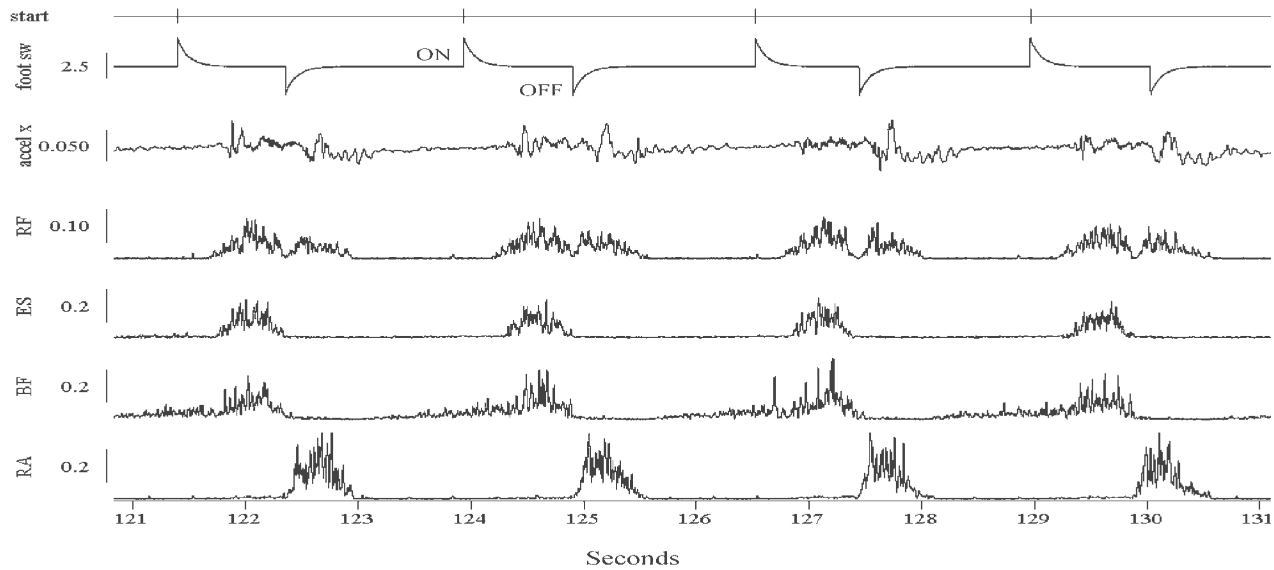

Figure 1. Example of data obtained for a sequence of rowing stroke obtained from one participant rowing on a Concept 2C during the 2 minute test (pace: 1.47min.sec·500m^{-1}, 24 stroke·min^{-1}). Top channel is the event trigger marker obtained from peak detection of footswitch recording (2nd channel) to indicate the start of the rowing cycle. The footswitch transients are shown in the second channel, with upward deflections indicating start of drive phase and downward deflections indicating beginning of recovery phase. Successive upward deflections are used to determine duration of rowing cycle. The 3rd channel shows the handle x-axis accelerometry record used to measure the onset of the stroke in the cycle. The other channels show sEMG activity as rms Amplitude from m. Rectus Femoris (RF), m. Erector Spinae (ES), m. Biceps Femoris (BF), and m. Rectus Abdominis (RA) respectively. X- axis scale is seconds. Y-axis scales show mV of sEMG for each muscle, and accelerometry and footswitch in Volts.

to the chest in the finish position. The handle is automatically retracted during the recovery phase, and a reversal in the pattern of movement of the lower limbs is observed, which includes in succession: ankle dorsiflexion, knee flexion, and hip and trunk flexion to reposition the rower's body in a forward flexed position ready to start the next cycle. The pattern of movement at the knee, hip and trunk observed from the videos of our participants were very similar for the Concept 2C and Rowperfect, despite the difference in the horizontal displacement of their body along the monorail.

Figure 1 shows typical data recorded in this study. Four consecutive rowing strokes collected on the Concept 2 are shown. The peaks of successive upward deflections indicated by "on" in the foot switch channel designate the start of the cycle. The downward deflection labelled "off" corresponds to the end of the drive phase/beginning of the recovery phase. The horizontal accelerometry recorded at the handle was used to measure the timing of the stroke during the rowing cycle. The root mean square amplitude of sEMG for the muscles: BF, ES, RF and RA recorded simultaneously are also shown in Figure 1.

The phasic pattern of hip and trunk extension and flexion is more clearly observed from the ensemble average profile of sEMG activity during the rowing cycle. Figure 2 shows an example of the profile from the same participant on the Concept 2C (Figure 2a) and on the Rowperfect (Figure 2b). There is clearly a similarity in the pattern of muscle activation between the two designs. During the drive phase there is activation of RF, ES and BF from 20% of the cycle. The cessation of activity in both ES and BF coincides with the end of the drive phase, while activity in RF continues to about 60% of the cycle. RA activity is observed around the end of the drive phase. Finally, BF is the only one of the four muscles where there is activity at the end of the cycle in the recovery phase and this continues into the start of the (next) cycle.

The effect of ergometer design on all the relevant measures obtained from the group of 6 elite rowers who participated in this study can be found in Table 1. The MANOVA undertaken in SPSS revealed no significant differerences for ergometer design on these relevant measures (Hotelling's trace = 1002.18, F=100.2, df= 1,10, and p = 0.078). There were no significant differences in average pace or stroke rate between the Concept 2 and the Rowperfect. The cycle duration and drive phase expressed as a percentage of the rowing cycle were also not significantly different between the two designs.

The handle accelerometry data, used to indentify the timing of the stroke in the rowing cycle, were not significantly different between the

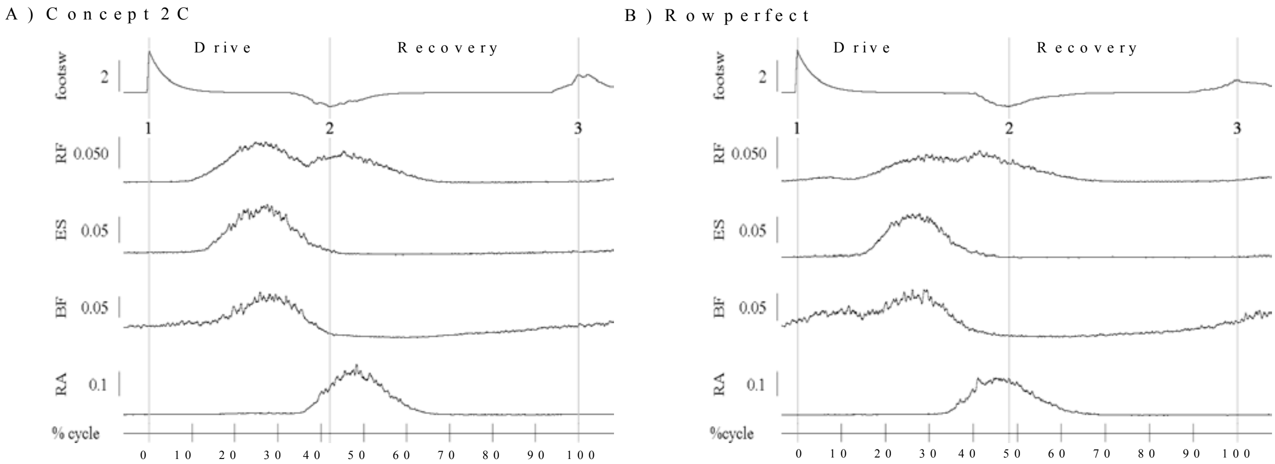

Figure 2. Example of ensemble average muscle sEMG profiles normalised in time as % of rowing cycle for a participant rowing on: A) Concept 2C at 1.47min.sec·500m^{-1}, 24 strokes·min^{-1} (n=39 strokes) and B) Rowperfect 1.47min.sec·500m^{-1}, 24 strokes·min^{-1}(n=40 strokes). Top channel is average footswitch trace (calibration bar is 2 V). Vertical cursors indicate duration of drive (1 to 2) and recovery phases (2 to 3) of rowing cycle. The calibration bars for each muscle are in mV and are matched for the two ergometers.

two ergometers. The latency of the peak horizontal acceleration for the Concept 2C was not significantly different from the Rowperfect. These correspond to the stroke starting at 24.9% (Concept 2C) and 21.3% (Rowperfect) of the rowing cycle.

We observed some variation in the number of clear peaks in the root mean square (rms) sEMG activity patterns (ranging from 1 to 3) during the rowing cycle, particularly for BF and RF. Therefore, we initially quantified overall muscle activity using the integrated EMG (iEMG) or area of the raw rms amplitude data over the rowing cycle for each muscle (see Table 1). In all of the four muscles examined, there were higher iEMG values for the Concept 2C, however, these were not significantly different from values obtained for the Rowperfect.

Metabolic load of rowing on two designs

The mean heart rate at end of the Concept 2C bout was not significantly different from the mean heart rate following the Rowperfect bout.

Video analysis of rowing cycle

The 2-D video analysis verified the coordinated

Table 1. Comparison of measures between Concept 2C and Rowperfect. Data are means (±SD, n = 6).

Parameters	Concept 2C	Rowperfect	Univariate F statistic (P value)
Ergometer monitor			
LCD Rowing Split time (s.500m^{-1})	106.8 (1.2)	106.5 (1.2)	.233 (.64)
Strokes rate (strokes·min^{-1})	23.0 (1.7)	23.7 (1.3)	.769 (.41)
Rowing cycle			
Cycle duration (sec)	2.57 (.04)	2.53 (.09)	1.09 (.32)
Drive duration (sec)	1.37 (.24)	1.36 (.23)	.003 (.96)
Drive phase (% of cycle)	53.0 (9.7)	55.3 (9.5)	.161 (.70)
Latency to handle peak	.64 (.18)	.51 (.18)	1.07 (.33)
Horizontal Accelerometry (sec)			
Heart Rate (beats·min^{-1})	162 (7)	169 (8)	2.002 (.12)
2-D video motion analysis			
Hip Range of Motion (deg)	101.6 (4.5)	99.5 (2.7)	.980 (.35)
Knee Range of Motion (deg)	118.3 (5.0)	115.8 (6.7)	.42 (.53)
Average Technical Score	3.16 (1.83)	3.83 (1.61)	.728 (.52)
sEMG activity per cycle			
iEMG of RF (mV·sec)	.081(.019)	.060 (.015)	4.355 (.06)
iEMG of BF (mV·sec)	.075 (.030)	.072 (.014)	.062 (.81)
iEMG of ES (mV·sec)	.067 (.032)	.048 (.019)	1.479 (.25)
iEMG of RA (mV·sec)	.047 (.019)	.042 (.022)	.235 (.64)

There were no significant differences.

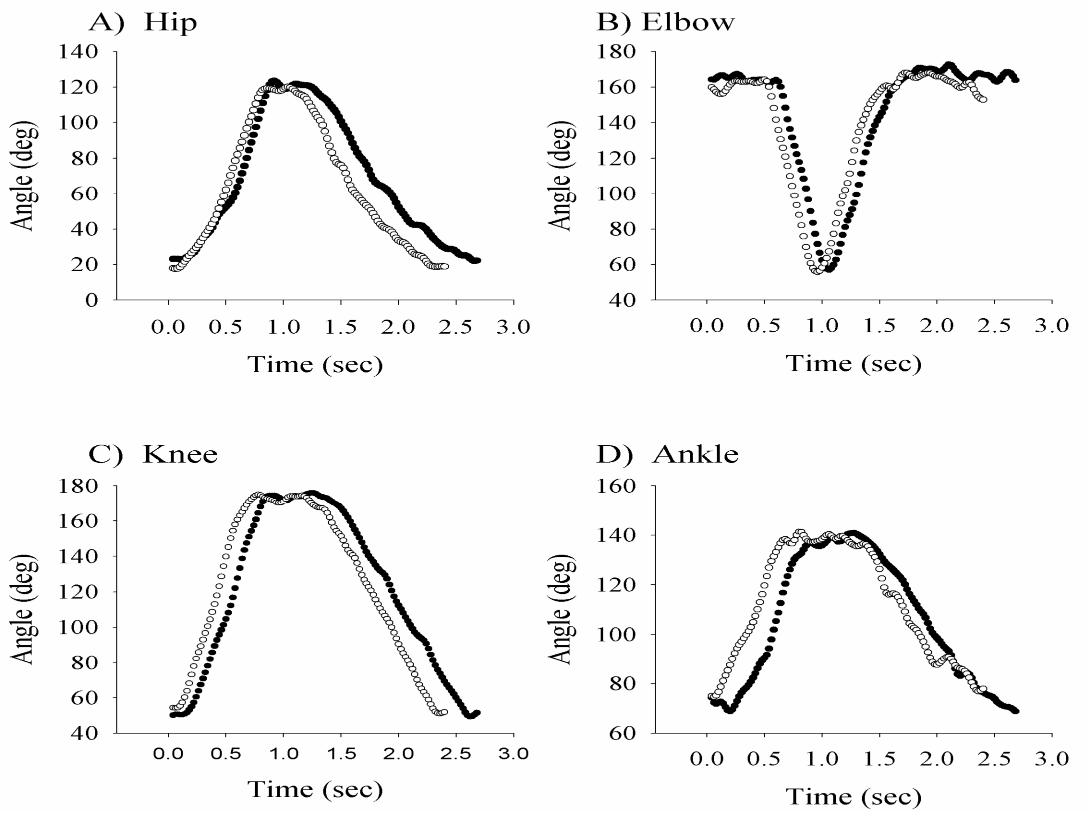

Figure 3. Examples of range of motion graphs obtained from 2-D (Peak-Motus) video motion analysis of one rower for Concept 2C (solid circles) and Rowperfect (hollow circles) during a representative rowing cycle. The graphs are for A) Hip, B) Elbow, C) Knee, and D) Ankle joints , respectively, with each point obtained from a frame by frame analysis (sample rate of 50 Hz) of the sequence.

movement of the hip and knee joints during the rowing cycle. An example of the hip, knee, ankle and elbow joint range of motion during the rowing cycle from one participant is shown in Figure 3. In this example the hip starts out in about 20 degrees flexion and moves through a range of about 100 degrees, while the knee starts out in 50 degrees of flexion and moves through a range of 118 degrees. The group mean hip and knee joint range of movement during the rowing cycle were not significantly different between the two designs (see Table 1). Although data were obtained from the elbow and ankle, these were not analysed for this study.

Technical analysis of rowing technique

An evaluation of the video footage conducted by one of the authors for technical proficiency for each rower revealed no significant difference in the overall scores obtained on each design (see Table 1).

Analysis of muscle activity during the rowing cycle

A comparison of the EMG activity patterns over the rowing cycle studied in the four hip and trunk muscles is summarised in Figure 4. The drive phase duration corresponds to approximately 54% of the rowing cycle and has been shown to be similar for both designs. Overall, the group mean profiles (means ± S.E.M.) for the four muscles studied show similar peaks of activity during the cycle. In term of earliest activity during the cycle, BF is clearly active from the onset of the cycle and remains active throughout the drive phase (Figure 4B). Although the pattern is similar for both ergometers, peak BF activity for the Rowperfect is earlier (15% of the cycle) than for the Concept 2C (25% of the cycle). BF activity falls at the end of the drive phase, and then increases again towards the end of the rowing cycle. The pattern of activity in RF is very similar for both designs, showing a broad peak of activity from 25% of cycle to 65% of the cycle (Figure 4A). For both designs, ES peak activity is evident at around 25% of the cycle and lasts to the end of the drive phase (Figure 4C). Peak RA activity occurs at 55% of the rowing cycle, corresponding to the end of the drive phase (Figure 4D).

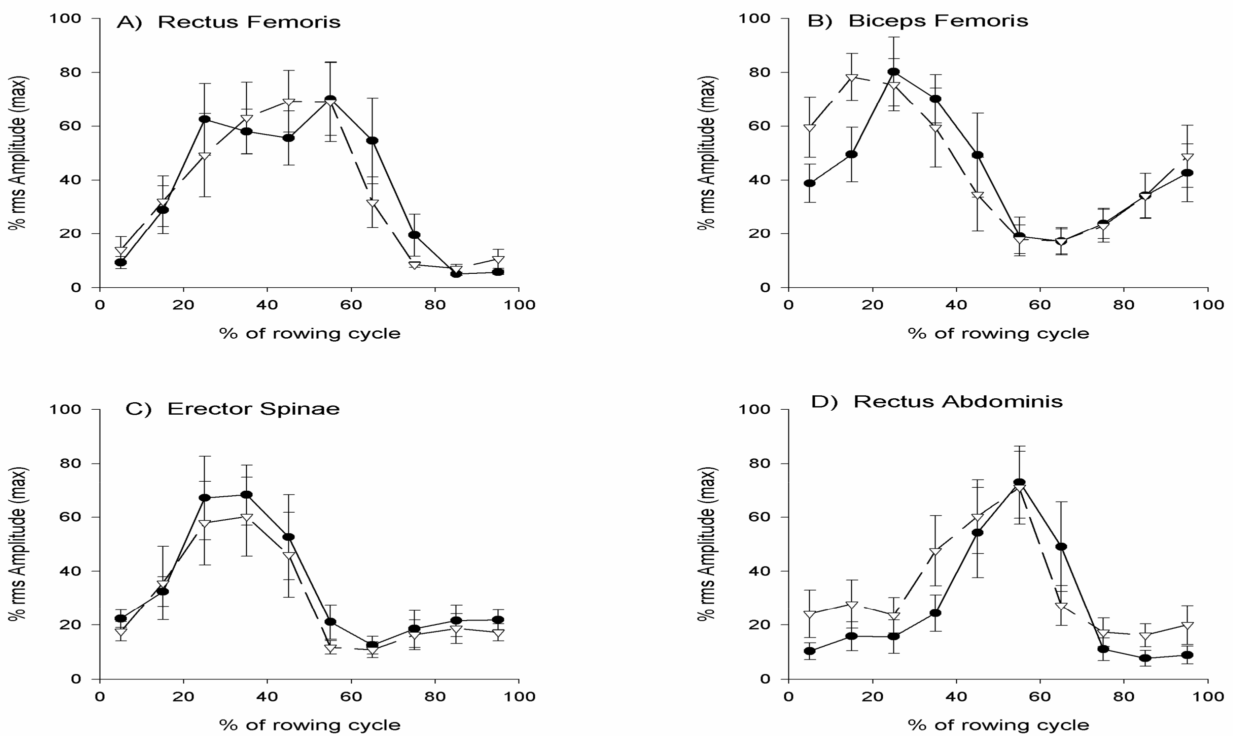

Figure 4. The group mean ensemble muscle activity profiles over the rowing cycle (Mean ± Standard Error of the Mean, n=6). Each point represents mean muscle amplitude for the 10% interval normalised to the group mean maximal rms amplitude detected over the rowing cycle for Concept 2C (filled circles, solid lines) and for Rowperfect (hollow circles, dashed lines). Each graph represents one of the four muscles studied: A) m. Rectus Femoris, B) m. Biceps Femoris, C) m. Erector Spinae, and D) m. Rectus Abdominis.

Repeated measures ANOVA of mean sEMG normalised rms amplitude per 10% intervals of the rowing cycle revealed no significant main effect of ergometer design (F= 0.070, df = 1,5, p = 0.802, η_p^2 = 0.014). There was no significant difference in sEMG activity for the muscle factor (F = 3.712, df = 3,15, p = 0.057, η_p^2 = 0.426), but a significant difference for the factor of 10% interval of rowing cycle (F = 10.25, df = 9,45, p = 0.006, η_p^2 = 0.672). In post-hoc comparisons, there were significant differences in sEMG at 50% and 80% and also 90% of cycle. There was also a significant two-way interaction of muscle by 10% interval of rowing cycle (F = 4.832, df = 27,135, p =0.039, η_p^2 = 0.491). The other two-way interaction factors were not significant: ergometer by muscle (F = 2.756, df = 3,15, p = 0.099, η_p^2 = 0.355) and ergometer by 10% interval of cycle (F = 1.862, df = 9,45, p = 0.207, η_p^2 = 0.271). Finally, the 3-way interaction effect of ergometer by muscle by 10% interval of rowing cycle was also not significant (F = 1.355, df = 1,27, p = 0.302, η_p^2 = 0.213).

DISCUSSION

The purpose of this study was to examine the possible differences in hip and trunk muscle activity under closely maintained rowing speeds between two of the most popular air braked training ergometers: the Concept 2C, a fixed power-head design and the Rowperfect, a floating power-head design. We observed no significant differences in power output, rowing cycle parameters, metabolic load, 2-D motion analysis, or technical proficiency in our study of 6 elite young male rowers. The lack of significant differences in these biomechanical and physiological measures justified further, the evaluation of ergometer design on hip and trunk rowing cycle muscle activity patterns.

Inspection of Figure 4 reveals the similarity between the two ergometer designs in the activity patterns of the four hip and trunk muscles examined in this study. This figure also illustrates the main outcome of the quantitative analysis undertaken here. Namely, that the muscle activity patterns with respect to amplitude and timing are very similar for both ergometer designs. This is not surprising given the close matching of the work maintained by the experienced rowers on the two designs. The significant differences detected in our analysis of the muscle by 10% interval of the rowing cycle interaction term indicate that these four muscles are differentially active, as expected in their contribution to movement of the hip and trunk. This is also consistent with their relative contributions to the phasic movement patterns of the hip and trunk during rowing. The extension/flexion cycle of hip and trunk motion was readily identified from the activity of the two major trunk muscles (e.g., ES and RA). The activation of ES contributes to lumbar trunk extension in the beginning of the drive phase, while activation of RA contributes to lumbar trunk flexion seen at the end of the drive phase. The activation of these two contribute to produce the smooth and distinct alternating pattern of trunk extension and flexion, as well as, undoubtedly serving to brake the speed of movement for the phasic change in direction necessary for the production of the rowing stroke. In addition, evaluation of the more complicated activity of the two bi-articular muscles (eg. RF and BF) studied here, also revealed no effect of ergometer design on their activity during rowing. The patterns observed in this study for the bi-articular muscles are consistent with a previous report revealing similar activity during the rowing cycle (Janshen et al. 2003). It can also be clearly seen that the broader area of activity during the rowing cycle in these muscles reflects their major contribution to knee and hip movement during the drive phase of the rowing cycle. Further study of the relative activity in the other thigh muscles should be undertaken to study the coordination of knee and hip activity during the rowing cycle.

The issue of safety has been raised by the biomechanical findings of the Bernstein et al. (2002) study comparing the work performed on the fixed and floating power-head configuration of a rowing ergometer. This interesting finding led us to examine this question using electromyography and to focus on the hip and trunk muscle activity during rowing. However, our study of elite male rowers shows that when the rowing effort is carefully matched, no significant differences in the levels of hip/trunk muscle activities were observed between the rowing on the Concept 2C or the Rowperfect. Our analysis is limited in that we have compared the rowing cycle sEMG patterns in non-fatiguing bouts of rowing. Subsequent investigation could focus on the possible underlying changes in muscle activity patterns seen with the onset of fatigue. It may also be of interest to examine the coordination of upper and lower limb activity as to whether they contribute to the changes in the stroke parameters observed by Bernstein et al. (2002).

In this study it was important to establish possible differences in hip/trunk muscle activity during rowing on the two different designs. We have determined that despite the clearly observed differences in horizontal displacement of the rower's body on the two ergometers, the activation patterns of the hip/ trunk muscles contributing to its phasic motion were essentially the same. Perhaps this is because in well-trained rowers the same ingrained pattern of movement is produced whether they are on an ergometer or in a boat. Neither of the two ergometer designs used here, simulate all aspects of the upper body motion required to move an oar in a boat and therefore do not simulate a vital technical component of stroke generation required for boat propulsion. Stationary ergometers also do not simulate the balance required of the crew in boat on the water. Further work utilising on-the-water rowing will no doubt, clarify these issues. However, unquestionably, ergometers do simulate the power output required for rowing on the water and will remain as essential training devices.

CONCLUSIONS

More work needs to be done before resolving the issue of the impact of high volume ergometer training on back pain in rowers. We believe that the results of the study here demonstrate that electromyographic techniques can be useful in examining the problem further. A combination of both electromyographic and biomechanical analysis should be undertaken to examine the impact of high volume training and the use of land-based ergometers. Our detailed study utilizing sEMG techniques has shown that both ergometer designs match the power output characteristics and underlying hip/trunk muscle activity patterns during the rowing cycle, and despite their limitations, both of these popular air-braked rowing ergometers are equally suited for land based training.

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DECLARATION

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KEY POINTS

- Possible differences in the muscle activity patterns due to ergometer design were investigated in a comparison of two popular air braked rowing ergometers: the Concept 2C (fixed power-head) and the Rowperfect (floating power head).
- No significant differences in group measures of metabolic load, rowing cycle parameters, integrated sEMG over the rowing cycle, or in 2-D motion analysis of hip joint excursion were detected between the two ergometer designs in rowers maintaining similar rowing pace during the two minute test (300W, or split time of 1:47min.500m^{-1}, 23 strokes.min^{-1}).
- No significant differences between the two ergometers were revealed using repeated measures ANOVA of ensemble average sEMG profiles normalised for both muscle activity and duration of rowing cycle in the four representative muscles: m. Rectus Femoris, m. Biceps Femoris, m. Erector Spinae and m. Rectus Abdominis.
- Evaluation of muscle activity of elite rowers training on the two designs suggests that they are equally suitable for rowing ergometer training.