THE ROWPERFECT ERGOMETER: A TRAINING AID FOR ON-WATER SINGLE SCULL ROWING

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Abstract

The purpose of this study was to compare rowing technique on the dynamic RowPerfect ergometer with a single scull. Eight national level rowers, performed on both the RowPerfect ergometer and in a single scull over 500 m, at rates of 24, 26 and 28 strokes/minute. Blade force and oar angle (on-water) and handle force and stroke length (on the ergometer) were measured. Both force and stroke angle/length were normalised from 0-100 (where 100 was the peak value). Body positions of the subjects at both the catch and finish of each of these rowing strokes were also compared for each stroke rate. The coefficient of multiple determination (CMD) was used to measure the consistency of force curves over a sample of five sequential strokes for each rower. Cross-correlations were performed between the left and right side on-water sculling force curves and a mean of these values with the ergometer curve for each rower. Stroke angle/length, which did not vary with rate, was similar for both forms of rowing. The CMD's showed a high consistency across the normalised strokes of each subject ($\approx$0.98). Cross-correlation values of 0.91, 0.92 and 0.93 were recorded between the force curves from the ergometer and on-water trials for stroke rates of 24, 26 and 28 strokes/minute, respectively. The mean trunk, thigh and lower leg angles at the catch and finish of the stroke were also similar across the stroke rates as determined by t-test. Results indicate that technique used on the RowPerfect ergometer was similar to that for on-water sculling, thus validating its use in off-water training.

Introduction

Rowing coaches over the centuries have endeavoured to modify technique in an attempt to increase boat velocity (Halladay, 1990). Much off-water rowing training, that is used in-part to improve technique during poor weather, is performed on various ergometers and these instruments are also being used to assist in crew selection. However, the technique of how a rower moves an oar through the water is thought to be different to that used to row traditional static ergometers (Steinacker and Secher, 1993; Torres-Moreno et al., 2000). With a static ergometer, when the rower's feet apply force to the foot-stretcher, and a reactive force is applied to the rower. As the foot stretcher is fixed, minimal propulsive force is lost as it is transferred to the rower's body equally and in the opposite direction to which is was applied. This fixed base for force transfer does not exist in a boat. The dynamic RowPerfect ergometer attempts to match the inertial forces of the ergometer with those recorded in a boat. The segment motion on this ergometer would therefore be more closely related to that of rowing on-water. The designer of the RowPerfect ergometer have reported that the force-time curves produced on the RowPerfect ergometer coincided well with the force-time curves produced in sweep rowing (Rekers, 1993).

Steinacker and Secher (1993) stated that there was a need to improve ergometer simulation of on-water rowing. Differences have been reported between on-water and ergometer rowing, both in terms of kinematic (Lamb, 1989) and kinetic (Martindale and Robertson, 1984; Smith et al., 1993) variables. While static ergometers may be useful for training physical fitness, they may also adversely alter the coordination of the muscles used in on-water rowing (Rekers, 1993; Dawson et al., 1998; Torres-Moreno et al., 2000). The study by Rekers (1993) also compared data from the RowPerfect ergometer to sweep rowers, and therefore data from single scull rowing are also needed.

This study compared the shapes of the force-length curves from high performance athletes rowing a single scull and a RowPerfect ergometer over three different stroke ratings. Intra-trial consistency of shape of the force curves is also reported for these two forms of rowing.

Methods

Definition of Terms

Button: collar that fits around the oar to prevent it from slipping through the gate.

Catch: nominally the time the onset of propulsive force on-water or handle force on the ergometer.

Drive: the phase of the rowing cycle where the athlete actively produces propulsive force on the oar handle and moves away from the foot stretcher.

Finish: nominally the end of the propulsive blade or ergometer force.

Gate: swivel in which the oar is mounted.

Heavyweight: a rower weighing greater than 72.5 kg (male) or 59.0 kg (female).

Recovery: during this phase of the rowing cycle, the athlete moves towards the foot stretcher.

Riggers: rigid structure that connects the gate (which holds the oar) to the boat. It allows the height and lateral distance of the gate to be adjusted to suit the rower.

Scull: rowing class in which each rower uses two oars, on separate sides of the boat, one held in each hand.

Sweep: rowing class in which each rower uses one oar, held in both hands.

Sample

Four male and four female national junior and Under 23 heavyweight rowers aged between 17 and 20 years acted as subjects.

Data Collection

A linear proximity system (based on changes in the electromagnetic field between iron and a magnet, which is recorded as a change in voltage) attached to *Croker* cleaver sculling oars, was used in the collection of on-water force measurements. The system provided information on: blade force (system located on the outboard, 0.25 m from the button of the oar) and oar angle (using potentiometers mounted on the oar gate and attached to a bracket on the oar). A similar system has been used by Smith et al. (1988, 1993 and 1994) for collecting oar force and position data on-water. The system varied in one major respect, in that the linear proximity transducers were positioned on the outboard side of the oar (closer to blade) to measure the blade force, rather than the inboard side of the oar (closer to handle) reported in previous research as a measure of handle force.

The instrumented oars and gates were linked to a slave computer, enclosed in a waterproof box in the boat. All incoming raw analog data were converted to digital form via an AX10400 12 bit 16SE 12.5 kHz analog to digital converter connected to a computer. Sampling of the on-board instrumentation was conducted at 160 Hz. Slave computer data were radioed to a master laptop computer carried in an accompanying speedboat.

The potentiometers were calibrated prior to every rowing session by using a calibration frame designed to fit the oar gate. The zero position was defined from a neutral point where the oar shaft was at a 90^0 angle to the longitudinal axis of the boat. From this neutral position, the movement of the oar handle towards the catch was defined as negative movement. The oar handle moving towards the finish was defined as positive movement. These potentiometers were then calibrated at –45, 0 and 45^0. A linear fit was applied to the calibration data for use as the scaling factor. Burnett et al. (2000) found the calibration of the oar angles using this system were reliable and within acceptable accuracy levels.

The linear proximity system mounted 0.25 m from the button on the outboard of each oar, was calibrated using a mass of 0 kg and 20 kg. The oar, positioned on a trestle and held firmly at the handle end and the first calibration reading of 0 kg was taken. A 20 kg mass was then placed 0.15 m from the outside edge of the blade (estimated blade centre of pressure) and the second calibration reading recorded. A linear fit was again applied to the calibration data. The dynamic linearity of the linear proximity system has also shown to be high with better than 0.3% RMS deviation from linear (Smith et al., 1988).

For the sculling data collection subjects warmed-up in the boat, maintaining a stroke rate under 24 strokes/minute for approximately 500 m as they rowed towards the start line. A Nielsen-Kellerman SpeedCoach™ was used to visually show subjects their stroke rating during the on-water trials. This was mounted on the boat decking and operated via a magnetic pick-up that detects seat movement, located under the sliding seat. Subjects were then instructed to row with maximum force over three 500 m distances. The order of the stroke rates (24, 26 and 28 strokes/minute) was randomised to eliminate any order effect. Each subject completed a 500 m trial at each of the stroke rates with a two minute rest between sets to eliminate fatigue effects.

For the RowPerfect ergometer trials subjects warmed-up on the ergometer, maintaining a stroke rate under 24 strokes/minute for a distance of approximately 500 m. Subjects were then instructed to row at maximum force over three 500 m trials. The order of the subject's stroke rate followed the same order as the on-water trials. Calculated handle force and stroke length was collected via the RowPerfect software. The handle force was calculated from the momentum exerted on the flywheel by the chain via a sprocket of know radius and is the sum of the frictional, inertial and elastic forces. These calculations were performed by the Rowperfect software based on the predetermined moment of inertia of the flywheel, the aerodynamic characteristics of the fan and the spring constant of the elastic system. Stroke length was calculated from the rotation of the flywheel. Ergometer rowers observed their stroke ratings and start/stop signals on the RowPerfect computer screen.

Both on-water and ergometer rowing were filmed using a Sony 8 (Model: TR 805-E) video camera mounted on a tripod for the ergometer trials, and hand-held with a stabiliser in a speed-boat for the on-water trials. Every effort was used to ensure the on-water video footage was conducted directly perpendicular to the rower. Spherical markers were attached to subjects at the following anatomical landmarks: shoulder (acromion process), elbow (lateral epicondyle), wrist (styloid process of the ulnar), hip (greater trochanter), knee (lateral epicondyle) and ankle (lateral malleolus). Footage was captured to computer at 25 frames/s and the body position at the catch and finish positions in the rowing stroke were digitised using s*iliconCOACH software* (SportPE Ltd., New Zealand). Trunk angle with respect to vertical, knee flexion angle and shank angle with respect to vertical was calculated at the catch position. Trunk angle with respect to vertical and thigh angle with respect to horizontal was calculated at the finish position.

Statistical Analysis

Force-angle (on-water) and force-length curves (ergometer) were normalised on a scale of 0-100, where 100 was the peak value (for both force and angle/length). A block of five sequential strokes were then chosen as representative, for the left and right hands during on-water sculling and from the RowPerfect ergometer. Coefficients of multiple determination (CMD) was used to compare the similarity of the five curves to quantify each rower's inter-cycle consistency. This technique has been recommended by Kadaba et al. (1989) and previously been used by Doyle (1999) to compare hand curves in rowing.

The comparison of normalised force-angle/length curves at the different stroke rates, between the on-water rowing and ergometer was performed using cross-correlation techniques. The computer program, SPSS (Version 8.0) was used to perform cross-correlations and also to perform repeated measure (stroke rate) analysis of variance on the various descriptive data. These descriptive data included the oar angle range and blade force for the on-water trials, the stroke length and handle force for the ergometer rowing and selected body positions throughout the stroke in both of the rowing modes. Where a significant main effect was recorded Scheffe post-hoc comparisons were performed to determine which rates were in fact different (Thomas and Nelson, 1996). A significant alpha level of 0.05 was chosen across all comparisons.

Results

The mean force-length and force-angle data from both the ergometer and on-water sculling are recorded in Tables 1 and 2 respectively. The average length of the RowPerfect strokes varied between 1.36 m –1.40 m and did not differ significantly with an increase in stroke rate ($F=1.26$; $p=0.30$). The mean on-water stroke-angle data did not vary between rates, with the average values exhibiting a narrow range of between 106° - 113° for the full stroke ($F=0.04$; $p=0.956$). The average body angles measured at the catch and finish positions of the stroke were statistically similar for both on-water and ergometer rowing, at each of the three stroke rates (Table 3 and Figure 1).

Table 1. Average maximum stroke length and force (± s.d.) obtained for the RowPerfect ergometer at various stroke rates (n=8)

	24 strokes/min		**26 strokes/min**		**28 strokes/min**	
	Length (m)	**Max. Force (N)**	**Length (m)**	**Max. Force (N)**	**Length (m)**	**Max. Force (N)**
Female	1.41 ± 0.02	349.41 ± 15.3	1.37 ± 0.05	348.06 ± 11.5	1.35 ± 0.10	356.5 ± 27.9
Male	1.40 ± 0.08	432.42 ± 95.2	1.40 ± 0.05	453.5 ± 64.4	1.36 ± 0.07	441.67 ± 78.3
Total	1.40 ± 0.05	390.91 ± 77.1	1.38 ± 0.05	400.78 ± 70.8	1.36 ± 0.08	399.08 ± 70.9

Table 2. Average maximum stroke force and oar angle range (± s.d.) obtained from the left and right oars of a single scull at various stroke rates (n=8)

	Stroke Rating (Strokes/min)	**Left Oar Angle Range (°)**	**Left Oar Max. Force (N)***	**Right Oar Angle Range (°)**	**Right Oar Max. Force (N)**
Female	24	101.11 ± 4.75	132.39 ± 8.51	98.98 ±7.42	124.54 ± 5.49
Male	24	119.68 ± 1.64	158.02 ± 13.48	114.88 ± 3.17	131.91 ± 15.13
Total	24	110.39 ± 10.46	145.21 ± 17.22	106.93 ± 10.01	128.23 ± 11.25
Female	26	101.71 ± 6.21	121.51 ± 15.46	96.92 ± 7.36	126.75 ± 12.84
Male	26	119.57 ± 2.97	163.78 ± 7.47	115.93 ± 4.77	131.53 ± 5.56
Total	26	110.64 ± 10.55	142.64 ± 25.23	106.43 ± 11.67	129.14 ± 9.51
Female	28	105.76 ± 4.85	122.60 ± 4.66	100.25 ± 4.25	140.38 ± 6.84
Male	28	119.49 ± 3.14	170.52 ± 11.41	115.55 ± 5.95	141.00 ± 1.89
Total	28	112.62 ± 8.26	146.56 ± 26.86	107.90 ± 9.48	140.69 ± 4.66

*A significant main effect was recorded ($p<0.01$) for the left and right oar forces. The left oar force was greater than the right at 24 and 26 spm.

The left hand blade force in sculling was consistently higher than the right hand force, though the standard deviation was also greater, meaning that the drive from this hand was not as consistent as that for the right hand (stats). The right hand force was also significantly higher at the rating of 28 when compared to 24 strokes/minute ($F=4.95$, $p=0.02$). Statistically similar levels of force were recorded on the RowPerfect ergometer at all stroke rates (stats) with the calculated handle force ranging from 318 N – 541 N.

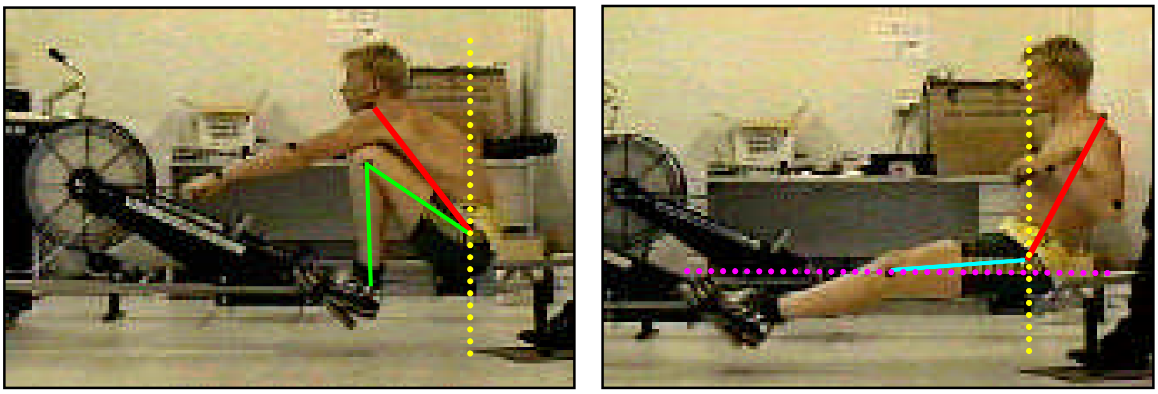

Figure 1 (a) & (b). Subject at the catch (a) and finish (b) positions on the ergometer

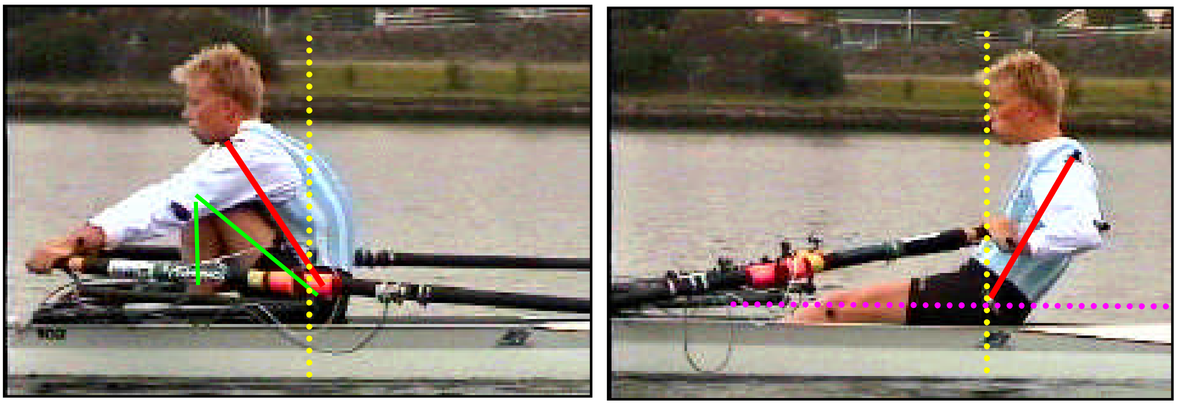

Figure 1 (c) & (d). Subject at the catch (c) and finish (d) positions on-water

Table 3. Mean body angle comparisons (±SD) across stroke rates (n=8)

		24 strokes/minute		26 strokes/minute		28 strokes/minute	
Position	**Angle (°)**	**On-water**	**Row-Perfect**	**On-water**	**Row-Perfect**	**On- water**	**Row-Perfect**
Finish	**Trunk**[1]	-31.6 ± 1.8	-32.0 ± 2.3	-32.5 ± 1.2	-32.6 ± 1.7	-32.2 ± 1.8	-31.9 ± 2.0
	Thigh[2]	4.1 ± 0.6	3.9 ± 0.8	4.3 ± 0.5	4.1 ± 0.4	4.0 ± 0.8	4.3 ± 0.7
Catch	**Trunk**[1]	31.8 ± 1.5	32.3 ± 1.8	32.4 ± 1.5	32.4 ± 1.6	32.0 ± 1.2	32.4 ± 1.7
	Knee[3]	50.9 ± 2.3*	52.5 ± 2.0	51.3 ± 2.3	51.0 ± 1.7	51.5 ± 2.0	51.0 ± 2.3
	Leg[4]	1.5 ± 3.1	1.1 ± 2.4	1.8 ± 2.5	1.8 ± 2.4	0.8 ± 2.4	1.1 ± 2.2

1. Trunk angle with respect to the vertical (clockwise is negative)
2. Thigh angle with respect to the horizontal
3. Knee angle is the included angle between the thigh and the leg
4. Leg angle with respect to the vertical (clockwise negative)

The knee angle recorded from the Rowperfect was significantly higher ($p<0.01$) than the on-water value at 24 spm.

The CMD from each of the five normalised force-angle/length curves indicated a high level of consistency for each subject, at each different stroke rate (Table 4). While the force-angle curves produced on-water were subject to variability of weather conditions, the level of consistency of the representative strokes was in fact similar (mean=0.98) to those recorded on the ergometer (mean=0.99). This consistency was not affected by stroke rate in either form of rowing. While the curves may have varied between subjects, each individual subject had a consistent pattern regardless of the side of the body. The results also indicated that the left and right force curves for each subject were highly correlated at the three different stroke rates of 24, 26 and 28 strokes/minute (0.97, 0.98 and 0.98 respectively: Table 5 and Figure 2).

Table 4. Mean coefficients of multiple determination across rowing techniques for each rate (n=8)

	24 strokes/minute			26 strokes/minute			28 strokes/minute		
	Left oar (on-water)	**Right oar (on-water)**	**Row-Perfect**	**Left oar (on-water)**	**Right oar (on-water)**	**Row-Perfect**	**Left oar (on-water)**	**Right oar (on-water)**	**Row-Perfect**
Mean	0.98	0.98	0.99	0.98	0.97	0.99	0.98	0.98	0.99
SD	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00

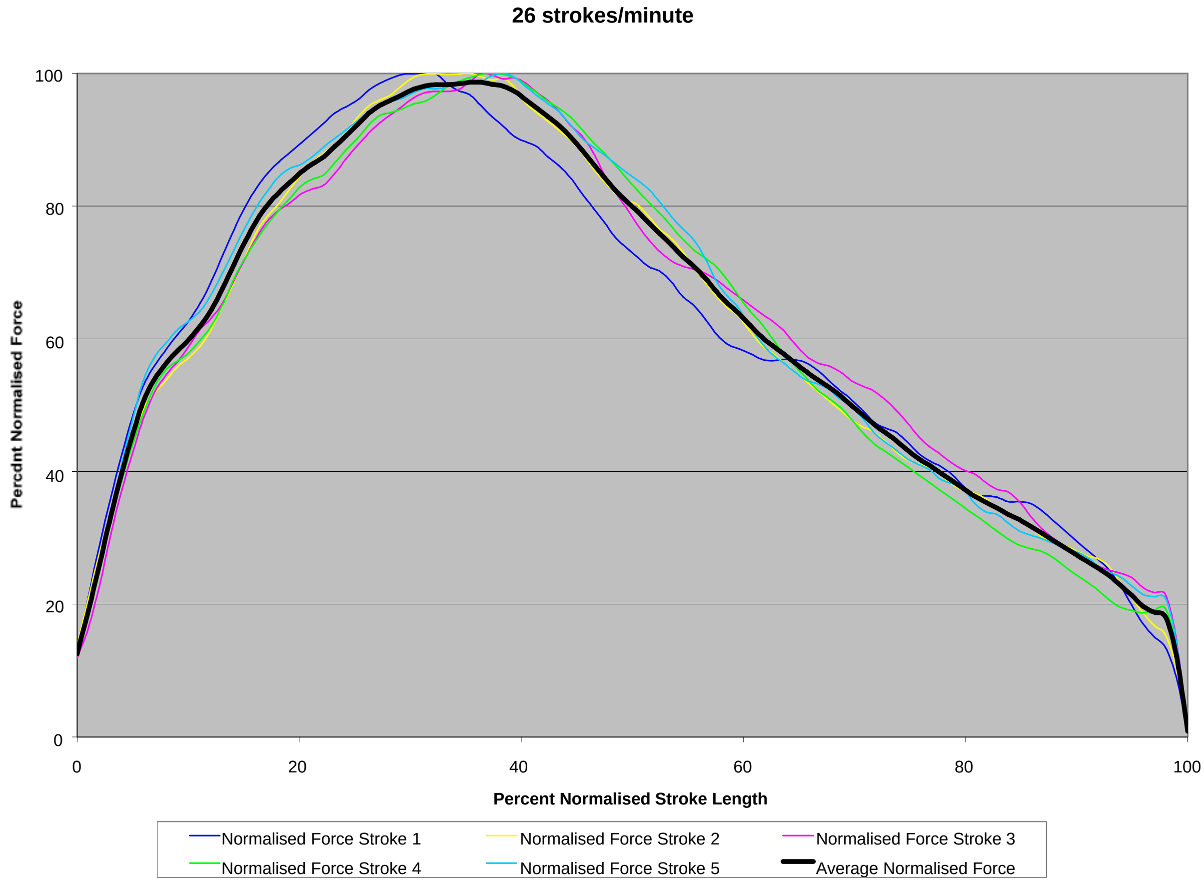

Figure 2. Normalised RowPerfect force-length curve.

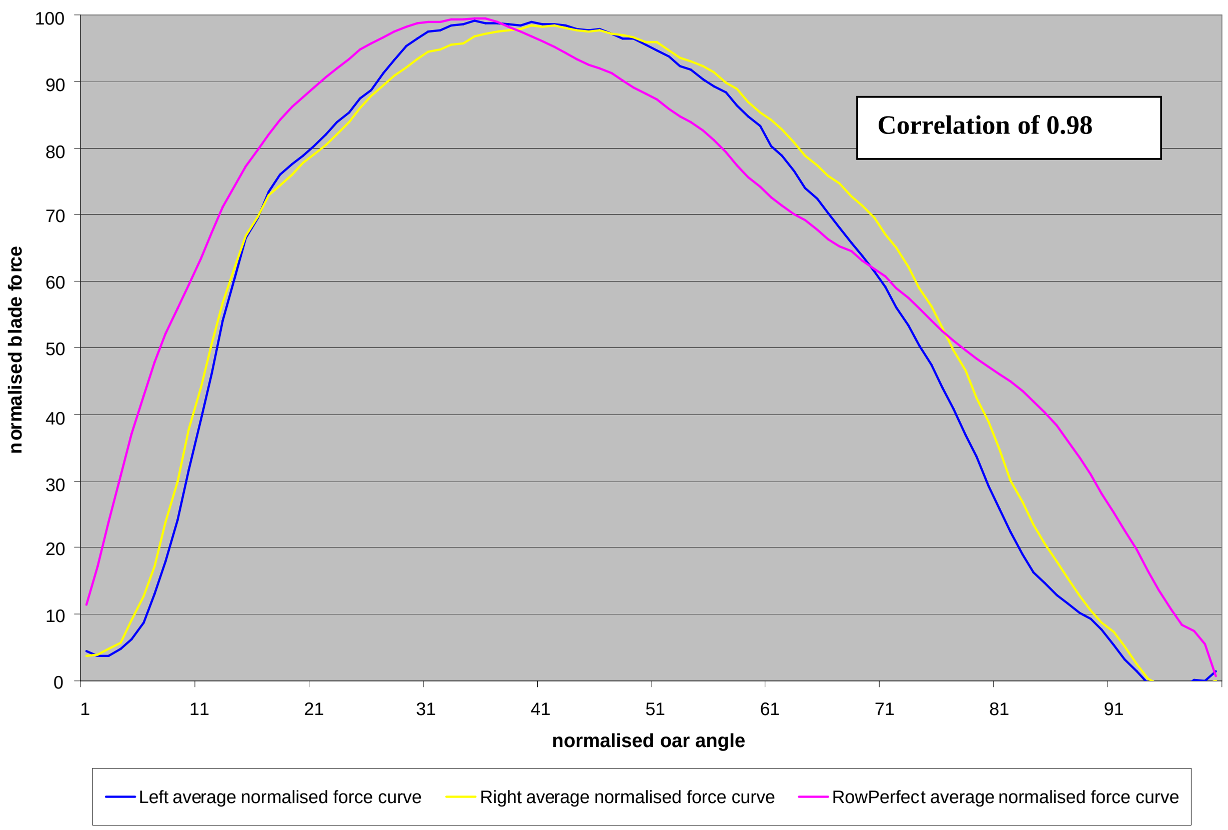

Figure 3. Comparison of on-water and ergometer force curves

Table 5. Cross-correlations between the left and right on-water force curves and between the combined on-water force curves with the RowPerfect force curves at the various stroke rates (n=8).

	Comparison of Left and Right On-water Curves			Comparison Between Combined On-water Curves and the RowPerfect Curves		
	24 strokes/ minute	26 strokes/ minute	28 strokes/ minute	24 strokes/ minute	26 strokes/ minute	28 strokes/ minute
Mean	0.97	0.98	0.98	0.91	0.92	0.93
s.d.	0.03	0.02	0.01	0.07	0.08	0.10

Discussions

The average length of the RowPerfect strokes varied between 1.36 m –1.40 m and did not change with increases in stroke rate. No current literature on stroke length on the RowPerfect ergometer is available. However, Dal Monte and Komor, (1989) reported that the total horizontal displacement of the handgrip for on-water rowing averaged 1.40 m. This is in agreement with data from the RowPerfect ergometer in this study where a mean of 1.38 m was recorded across all stroke rates.

The mean on-water stroke-angle, which did not vary statistically between rates (106.4^o-112.6^o for the full stroke) were higher than the 96^o-100^o reported for elite female scullers by Loschner and Smith (2000). This higher range may be influenced by the inclusion of male rowers in this sample. For example the females in this study, at a stroke rate of 24, had an angle range between 97.01^o-106.51^o, compared to that for males of 118.09^o-121.76^o. The maximum (45.5^o - 47.48^o,males and females respectively) and minimum (-60.9^o - -65.1^o males and females respectively) angles provided information about the finish and catch of the rowing stroke respectively. These data were in agreement with data from Loschner and Smith (1999). While the mean minimum angle in this study was slightly higher than those reported in the literature (with values of -64.1^o to –65.1^o), this can again be attributed to the fact that this study incorporated data from heavyweight male rowers. These males are generally taller than lightweight male rowers, and therefore would normally have a longer reach at the catch.

Values for maximum force measured from the blade of the oar, ranged from 107.30 N-187.04 N. These figures could not be compared to the literature, as no literature on blade force could be found. The majority of force values reported in the literature were derived from the force at the handle. These values are typically 500 N (Sanderson and Martindale, 1986). The strain gauges or linear proximity sensors used in the majority of published studies (Schnider et al., 1978; Smith et al. 1993; Smith & Spinks, 1989) have been placed on the inboard of the oar, whereas in this research, measurement occurred distal to the gate of the oar.

A recent study by Buck et al. (2000) examined the peak ergometer handle force on a static and dynamic Concept II ergometer and a RowPerfect ergometer. Thirteen national level male and female rowers performed six one-minute workloads at various power outputs, with the handle force measured using a load cell in series with the ergometer chain and handle. The average peak horizontal handle force varied from 575 N to 970 N, which was not significantly different from values obtained for the static and dynamic Concept II ergometers (Buck et al., 2000). These handle force values were substantially higher than the forces recorded in the current study, which ranged from 318 N – 541 N. The reason for the discrepancy between the two studies cannot be fully explained other than that the current study uses a calculated handle force from the RowPerfect system, whereas the research of Buck et al. (2000) directly instrumented the handle.

Body angles measured during each stroke cycle were in general similar for both on-water and ergometer rowing (Table 3). These angles, were also similar to data found by Schultz (1994) on an instrumented Concept II ergometer. There was no previous literature that reported body position kinematics for the RowPerfect ergometer.

While the force-angle curves produced on-water were subject to variability of weather conditions, the level of consistency of the representative strokes was in fact similar (mean=0.98) to those recorded on the ergometer (mean=0.99) as measured by the CMD. This consistency was not affected by stroke rate in either form of rowing. While the curves may have varied between subjects, each individual subject had a consistent pattern regardless of the side of the body.

The results indicated that the left and right force curves for each subject were highly correlated (Table 5). While the curves varied between subjects, each individual displayed a ”signature” trace (Smith et al., 1988, pg. 11). Figure 3 is an example of the level of consistency between the representative force-angle curves for both on-water and RowPerfect data. The combined normalised left and right force curves were highly correlated with the RowPerfect force curves (Table 5). Only two individual values fell below 0.8, while the majority of scores were above 0.9. The correlation increased as the stroke rates increased, from a mean of 0.91 to 0.93.

From the high correlation between the on-water and RowPerfect curves, it may be assumed that the RowPerfect does, in part, replicate the movement patterns of on-water rowing. While such measures of stretcher force, joint moments and muscle activity was not assessed, a transfer of learning may apply across the two forms of rowing, as they demonstrate similar elements (force curves) during performance of the skill (Magill, 1980). While the controlled structure of the RowPerfect ergometer may differ from the unpredictable environment found for on-water sculling, the basic patterns of the force curves are similar.

Conclusions

It can be concluded that rowing on the RowPerfect ergometer produced similar shaped force curves to single scull rowing. The five sequential normalised force curves for the right and left hands in sculling were similar, as were curves recorded on-water and from the ergometer. Body positions of the rowers at the catch and finish were generally not significantly different between these forms of rowing and data did not alter substantially for an increase in stroke rate. As the aim of rowing on an ergometer is often for specific training and even crew selection, it is necessary that this be done on an ergometer that has a 'rowing structure' as similar to on-water rowing as possible.

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