QUANTITATIVE CHARACTERISTICS OF COXLESS PAIR-OAR ROWING

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The rowing technique that produces efficient propulsion of pair boats is difficult to master due to asymmetries in the mechanical layout. The pattern of force production on the oar depends on whether the rower is in the bow or stern seat. In common with other sweep oar rowing, there are right-left asymmetries in the application of external forces to the rower's body. In this paper these predictions were tested in an instrumented pair. The increased magnitude of the propulsive pin force for seat 2 at the beginning of the drive phase and the same for Seat 1 for the second half of the drive phase was borne out by measurements. Asymmetries, which require different muscle characteristics for the left and right leg, were also observed. Both outcomes imply that coaches should look for different strength characteristics in the seat 1 and seat 2 rowers.

KEY WORDS: rowing, pin forces, stretcher forces, pair boat.

INTRODUCTION: Coxless pair-oar rowing is the most technically difficult of the classes of rowing boat in international competition (Morrison, 1987). This is partly due to the combination of sweep-oar rowing asymmetry and the particular patterns of application of forces required due to the position of the two rowers in the boat. In a pair boat there are two rowers with one oar each. The oars are placed on opposite sides of the boat and with one towards the stern (seat 2) and the other towards the bow (seat 1). Forces are applied to the pins via the oar and to the stretcher (foot plate) via the feet. The propulsive pin forces, if equal, create equal but opposite moments whereas the transverse pin forces even if equal create a net moment about the vertical axis of the boat. For a "stroke-side stroke" rigged boat the net moment will be anti-clockwise (looking from above) during the first half and clockwise during the second half of the drive phase if the rowers have the same timing and magnitude of forces. For propulsive efficiency it is important to have the boat pointing as steadily towards the finish line as possible (Smith and Loschner, 2001) and thus pair rowers manipulate the pin forces and stretcher forces to help counteract this turning moment. The asymmetry also places differential stresses on the muscle of the pin-side and off-side of the rower's body. Kramer and Leger (1991) reported significantly greater knee extension strength for the pin-side compared with the offside legs of lightweight sweep-oar rowers but non-significant but reversed differences for heavyweight sweep-oar rowers. Analysis of morphometric data in the left deltoid muscle by Roth et al. (1993) demonstrated higher fast twitch fibre content and lower oxidative fibre capacity and fibre areas in the seat 2 rowers. The external forces causing these asymmetries have been quantified for oar normal forces only (Roth et al., 1993) and not for stretcher forces. The purpose of this paper was to describe quantitatively the external forces acting on the pair boat that affect boat propulsive efficiency and the asymmetrical stress on the rowers themselves arising from the stretcher forces.

METHODS: Ten elite level (international) male rowers, in 5 pairs, rowed a pair boat at a steady state cadence of 32 strokes per minute. A pair boat was instrumented with sensors that measured the following performance variables. Pin force data were sensed using three-dimensional piezo-electric transducers (Kistler, Switzerland). The pin was mounted on the rigger and was the axis of rotation for the gate or rowlock that holds the oar. The force in the propulsive direction was recorded from the stretcher with two shear-beam load cells (Transducer Techniques, USA). The shear beam load cells were mounted at the ends of the top bar so that an indication of relative force applied by the pin-side and offside foot could be gauged. The vertical and horizontal oar angles were measured by low-friction potentiometers and a fibreglass arm attached to the inboard end of the oar so that the oar was free to rotate around its longitudinal axis. Three accelerometers (Analog Devices, USA) and three gyroscopes (Murata, Japan) sensed the acceleration and orientation of the boat along and around the three axes of the boat. All variables were sampled at 100 Hz and the data telemetered (pocketLAB, Digital Effects) to a shore-based receiver and laptop computer (4700CT, Toshiba). Subsequent to collection, the data was loaded into analysis software, and a sequence of at least 15 strokes selected. The time series for the pin and stretcher forces were time-normalised and averaged. The values for peak pin and stretcher forces and their timing for each stroke were detected and averaged over strokes for each rower. t-tests were used to indicate the significance of differences between the groups of scores.

RESULTS AND DISCUSSION: The mean height and weight of the rowers was 186.9 ± 6.1 cm and 83.0 ±10.6 kg respectively. The mean stroke rate was 31.9 ± 0.3 strokes per minute. *Pin forces:* The pattern of propulsive force production on the pin observed in pair-oared rowing (Figure 1) was consistent with the requirements of rotational equilibrium about the vertical axis of the boat proposed by Korner and Schwanitz (1987, p 104) and with the results reported by Roth et al. (1993).

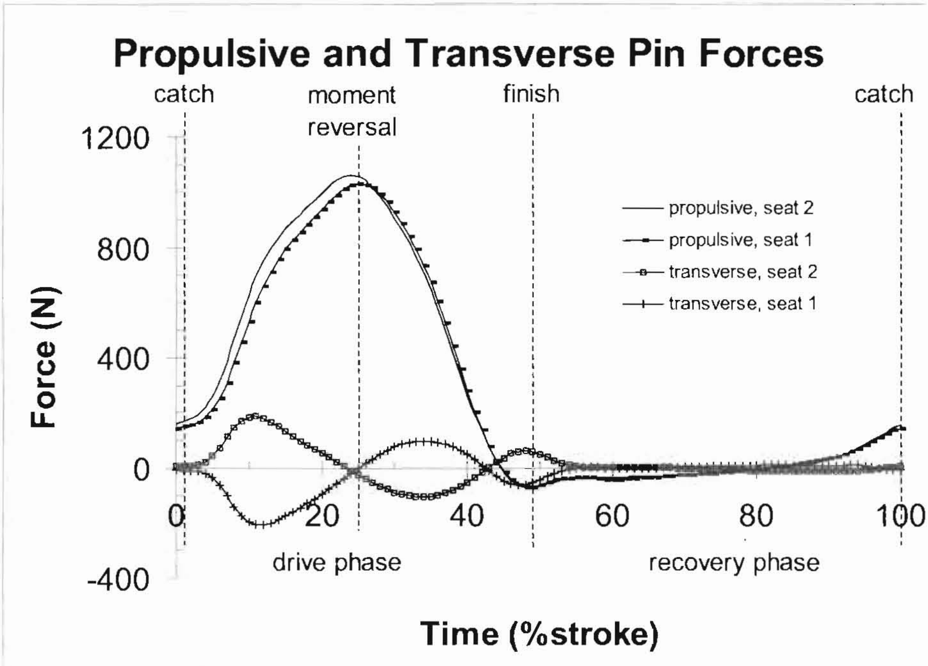

Figure 1. Average propulsive and transverse pin forces for elite level rowers. Seat 1 is closest to the bow of the boat. The propulsive and transverse seat 2 pin forces lead the seat 1 forces during the drive phase. The signs of the forces are drawn as if all rowers were in the "stroke-side stroke" configuration.

On average, the rower in seat 2 applied the force to the handle of the oar about 1% of the stroke (19 ms) earlier than the rower in seat 1. In the first half of the drive phase this imbalance in the propulsive force applied to the pins amounts to a clockwise moment (looking from above) and helps to counteract the anticlockwise moment caused by the transverse pin forces. As the transverse forces change from inwards to outwards at about 25% of the stroke, so the imbalance in the pin forces changes from seat 2 greater than seat 1 to seat 2 less than seat 1 thus helping to maintain rotational equilibrium. This transitional point in the drive phase is marked "moment reversal" in Figure 1. The earlier timing for seat 2 of the peak propulsive pin force was worth noting even though $p > 0.05$ (Table 1). There was no significant difference in the magnitudes of the peak propulsive pin forces.

Table 1. Means, standard deviations, and significance of differences for magnitude and time of peak propulsive pin force.

	Peak Propulsive Pin Force			
	Force (N)		Timing (%stroke)	
	Seat 1	Seat 2	Seat 1	Seat 2
Mean	1120	1076	23.0	25.4
SD	104	100	2.8	1.5
p-value for difference	0.26		0.07	

Stretcher forces: The pin-side stretcher force began the drive phase with greater amplitude and reached its peak earlier than the offside stretcher force (Figure 2). However, the offside stretcher force reached about 20% greater peak value later in the drive phase. The patterns and magnitudes were very similar for the left side of seat 1 and the right side of seat 2 and vice versa. The average of both seats for the pin-side and offside force time series were drawn in Figure 2. The stretcher forces were far from symmetrical and both magnitudes and timing of peak forces were significantly different (Table 2). The higher pin-side force up to about 20% of the stroke would have exacerbated the tendency of the transverse forces to rotate the boat anti-clockwise but they have very small moment arms about the centre of mass of the boat (~ 0.02 m). The different patterns of forces were most likely due to the posture of the sweep oar rower where the rotation of the trunk towards the pin at the beginning of the stroke brings the direction of force more over the pin-side leg. The magnitudes of the forces have contrary implications for leg strength to those reported for light-weight rowers by Kramer and Leger (1991) but the same for heavyweight rowers.

Table 2. Means and standard deviations for time of peak propulsive pin force, time and magnitude of pin-side and off-side stretcher forces.

	Peak Stretcher Forces (N)				Timing of stretcher forces (%stroke)			
	Seat 1		Seat 2		Seat 1		Seat 2	
	pin-side	off-side	pin-side	off-side	pin-side	off-side	pin-side	off-side
Mean	461	571	428	535	19.8	25	19	27.8
SD	51	68	63	61	3.0	2.6	2.8	2.8
p-value for difference	0.009		0.05		0.01		0.0005	

CONCLUSION: There are significant asymmetries in the application of pin and stretcher forces during the rowing of a pair boat. Some of these asymmetries are aimed at maintaining an efficient boat orientation during the stroke and are therefore important indicators of effective rowing technique. Examination of the timing and magnitude of the propulsive pin forces would be an important aspect of the selecting and coaching of pair crews. The asymmetry of application of stretcher forces creates widely different strength requirements of the knee and hip extensors for the left and right side of the body. In summary, the seat 2 rower overall and the offside leg of both rowers should have greater speed strength than the seat 1 rower overall and the pin-side leg of both rowers.

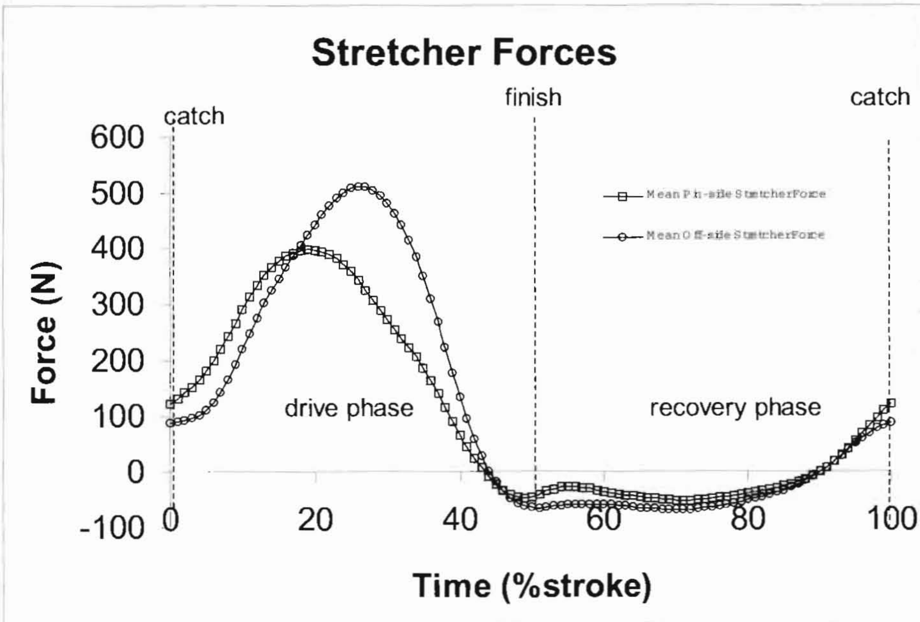

Figure 2. Pin-side and off-side stretcher forces. Each graph is the mean for seat 1 and seat 2.

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