CONTROLLING YAW IN A PAIR ROWING BOAT

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Efficiency in propelling a rowing boat is important in competitive rowing as, for a given power output from the rower, the more efficient the rower is the faster the boat will go for a given power output. One factor that may influence the efficiency is the pointing direction of the boat and how well this is maintained directly towards the finish line. Rudder corrections or movement off this line increases the water drag. The balance of forces acting on the boat in the horizontal plane contribute to the moment acting on the boat around a vertical axis. To measure this effect a pair boat was instrumented to measure the velocity of and the major horizontal plane forces acting on the boat. Five male elite pair crews rowed the pair boat maximally at 32 strokes per minute. Individual differences were seen in the net angular impulse imparted to the boat and these were correlated with rowing efficiency. Thus the minimisation of angular impulse is an important aspect of pair rowing technique.

KEY WORDS: rowing, pin forces, stretcher forces, pair-oared boat, boat moment

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 placement of the two rowers in the boat and resulting application of forces to the boat. In a pair boat there are two rowers with one oar each. The oars are placed on opposite sides of the boat but 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 pair rowers manipulate the pin forces and stretcher forces to help counteract the turning moment.

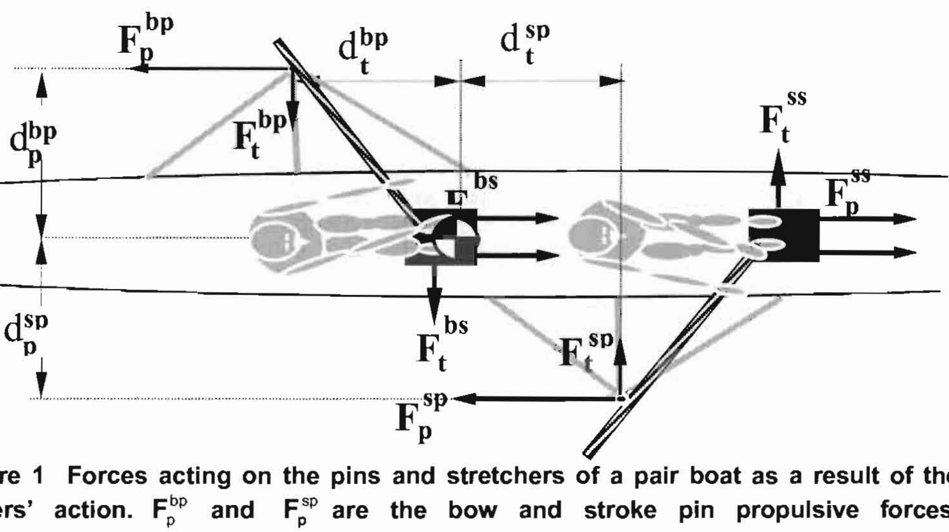


Figure 1 Forces acting on the pins and stretchers of a pair boat as a result of the rowers' action. F_p^{bp} and F_p^{sp} are the bow and stroke pin propulsive forces, F_t^{bp} and F_t^{sp} the pin transverse forces, F_p^{bs}, F_p^{ss}, F_t^{bs} and F_t^{ss} the stretcher forces. The relevant moment arms are indicated by the letter d.

At the time of the data collection for this paper it was possible to measure, on-water, the transverse and propulsive pin forces and the propulsive stretcher forces but not the transverse stretcher force. The seat forces in the horizontal plane were considered to be zero. So, taking into account the air and water resistance, the equations of motion were:

$$m^{boat}a^{boat}_{propulsive} = F^{stroke\ pin}_{propulsive} + F^{bow\ pin}_{propulsive} + F^{stretcher}_{propulsive} - \left(F^{air\ resistance}_{propulsive} + F^{water}_{propulsive}\right) \quad \text{Eqn 1}$$

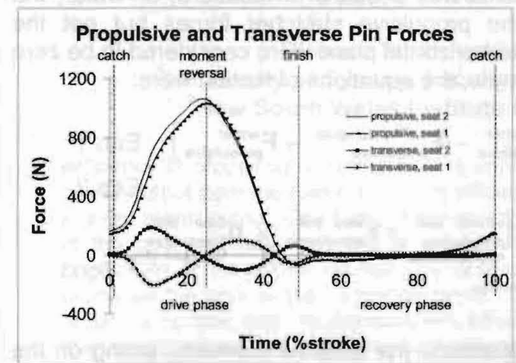
$$m^{boat}a^{boat}_{transverse} = F^{stroke\ pin}_{transverse} + F^{bow\ pin}_{transverse} \quad \text{Eqn 2}$$

$$I^{boat}_{z}\alpha = F^{bow\ pin}_{propulsive} \times d^{bow\ pin}_{\substack{propulsive\\ moment\ arm}} - F^{stroke\ pin}_{propulsive} \times d^{stroke\ pin}_{\substack{propulsive\\ moment\ arm}} + F^{bow\ pin}_{transverse} \times d^{bow\ pin}_{\substack{transverse\\ moment\ arm}} - F^{stroke\ pin}_{transverse} \times d^{stroke\ pin}_{\substack{transverse\\ moment\ arm}} - M^{water\ reaction}_{z} \quad \text{Eqn3}$$

The purpose of this paper is to describe quantitatively the external moments acting on the pair boat that affect boat propulsive efficiency and compare these characteristics in rowers from the elite level of competition.

METHODS: Ten elite rowers, in 5 pairs, rowed an instrumented pair boat at a steady state cadence of 32 strokes per minute. The pair boat was instrumented with sensors. 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. Only the boat propulsive force was recorded from the stretcher or footplate 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 the force applied by the stretcher to the pin-side and off-side of the boat could be measured. A magnetic turbine and inductive pick-up provided the data for the velocity 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 net applied moment and its impulse over the stroke were computed. Angular impulse was chosen to represent the effect of the moment on the boat in influencing the angular momentum in the horizontal plane. Efficiency was calculated by dividing the mean velocity cubed by the total work done on the boat. Correlation between the angular impulse and efficiency was investigated.

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. The moment arms for the propulsive and transverse pin forces were 0.86 m and 0.69 m respectively. For a stroke-side rigged boat (Figure 1) the horizontal plane moments produced by the transverse pin forces will both be anti-clockwise (positive) for the first half of the drive phase and clockwise for the second half of the drive phase. To counteract this, the stroke rower must produce a propulsive pin force that is $\frac{0.69 \times \left(F^{bp}_{t} \times d^{bp}_{t} + F^{sp}_{t} \times d^{sp}_{t}\right)}{0.86}$ greater than the bow pin propulsive force in the first half of the drive phase and the opposite in the second half.



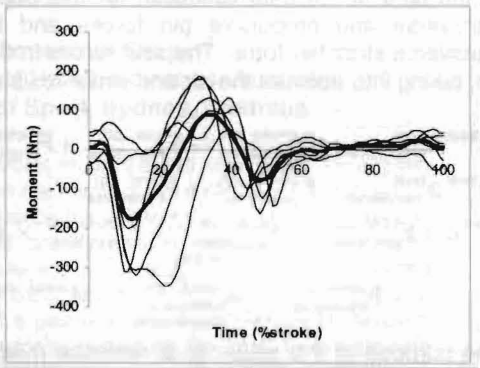


Figure 2 Average propulsive and transverse pin forces for elite level rowers. Seat 1 is closest to the bow of the boat. The propulsive and transverse seat 2 pin forces lead the seat 1 forces during the drive phase. The signs of the forces are drawn as if all rowers were in the "stroke-side stroke" configuration.

Figure 3 Net applied boat moment for all the pairs (light lines) and the mean (thick line). None of the pairs were able to keep the applied moment below 100 Nm for the whole of the stroke.

The mean pattern of propulsive force production on the pin observed in pair-oared rowing (Figure 2) for the elite rowers tested was consistent with attempts to maintain rotational equilibrium about the vertical axis of the boat as also proposed by Korner and Schwanitz (1987, p 104) and with the results reported by Roth et al. (1993). On average, the rowers 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 amounted to a clockwise moment (looking from above) and helped to counteract the anticlockwise moment caused by the transverse pin forces. As the transverse forces changed from inwards to outwards at about 25% of the stroke, so the imbalance in the pin forces changed 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 2.

However, as Figure 3 shows, this timing difference was not large enough to entirely eliminate the moment applied to the boat. On average, the moment (peak moment = 170 Nm) was such as to rotate the boat anticlockwise for "stroke-side-stroke" rigged boat in the first half of the drive phase and the opposite (peak moment = 90 Nm) for the second half of the drive phase.

Individual differences were large (Figures 3 and 4). The graphs of the pair illustrated on the left show that it would be practically possible to bring the moment to zero through appropriate timing of the pin propulsive forces. The pair on the left actually overcompensated and produced a clockwise moment in the first half of the drive phase. This could be predicted from the timing differences that are obvious in the propulsive pin forces. The pair illustrated on the right had the most optimal timing of this sample of pair rowers. This pair had the least fluctuations in the moment of the elite group. Figure 3 shows the wide range of amplitudes and timings of the net applied boat moment in the horizontal plane.

The question remains: What significance do these mechanisms and results have for pair rowing performance? To answer this question a measure of the efficiency of the pairs was calculated and compared with the angular impulse using correlation. The angular impulse explained about 50% of the variance in the efficiency (r^2 = 0.48) but there was a 20% probability that this was by chance (p = 0.19). The sample size (n = 5 pairs) was small and greater numbers would help to clarify this result.

The argument that the efficiency of pair rowing is improved by maintaining the moment close to zero has a sound mechanical basis. If there is a net angular impulse, the boat will tend to execute a net angular displacement for reach stroke. This effect would have to be counteracted by the stroke rower by applying sufficient rudder to keep the boat pointing towards the finish line on average. This will create extra drag and require more work per stroke to maintain a given velocity. The shear forces on the stretcher were not measured in this study. However, this would make a difference in the magnitude and timing of the corrective forces not in the principle of reducing the net moment to zero throughout the stroke.

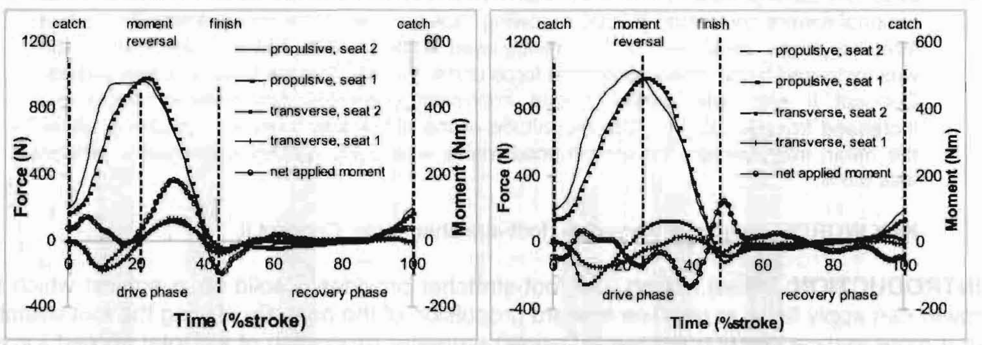


Figure 4 The components of the net applied boat moment in the horizontal plane for pair boats. The pair on the left demonstrates overcompensation. The pair on the right had the most optimal strategy of this group of rowers.

CONCLUSION: Highly accurate asymmetrical timing is required of the two rowers in a pair boat if the net moment applied to the boat is to be minimised. This is a desirable goal as this study suggests that there is a link between rowing mechanical efficiency and the angular impulse applied to the boat. More data needs to be collected from a larger sample to confirm or refute this assertion. Examination of the timing and magnitude of all the forces acting in the horizontal plane and their net effect on the moment applied to the boat about a vertical axis would be an important aspect of biomechanical input to the coaching of pair crews.

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