THE EFFECTS OF HORIZONTAL AND VERTICAL FORCES ON SINGLE SCULL BOAT ORIENTATION WHILE ROWING

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Forces produced at the oarlock pins and the foot stretcher, and the orientations of a single scull rowing boat, were investigated in eleven male rowers. Rowers were tested at 32 strokes·minute^{-1} on an instrumented single scull boat. The pitch of the boat was shown to be increased by the vertical forces applied to the pin and the foot stretcher, and roll was increased by an imbalance of vertical forces delivered to the bow and stroke side pins. Pitch and roll were largest in the late recovery and early drive phase when forces applied to the boat were greatest. It is suggested that the provision of feedback on boat orientation and force production may enable rowers to be trained to reduce changes in orientation and therefore to reduce energy loss through hydrodynamic drag.

Keywords: biomechanics, kinetics, on-water rowing,

INTRODUCTION: Boat orientation is a vital component to maximising the overall velocity of the boat by reducing the drag forces that act on the hull of the boat during the stroke. Drag forces acting on the boat depend upon the frontal area of the shell relative to the water and are also increased by wave motion caused by changes in orientation (Baudoin and Hawkins, 2002). Therefore, by increasing oscillations in boat orientation in the water, the drag forces present throughout the stroke will be increased. Increases in drag forces that act on the boat throughout the stroke have to be overcome by the rowers before they are able to accelerate the boat (Nolte, 1991). Forces acting on the foot stretcher and oarlock pin have specific effects upon the pitch, roll and yaw of the boat. Changes in boat orientation act to increase the cross sectional area of the boat in the water and thus increasing the drag forces acting on the hull of the boat (reference). The purpose of this study was to quantify the changes in boat orientation during single scull rowing and to investigate the forces responsible for these changes.

METHODS: Eleven male rowers (age 18.5 ± 1.9 years, height 1.87 ± 0.04 m and body mass 82.3 ± 8.2 kg), consisting of national, state and university competitors, participated in the study. Training frequencies ranged from 6 - 10 sessions per week, with all rowers training for both sweep rowing and sculling. Participants were requested to row at 32 strokes·minute^{-1} and were provided with visual information feedback of stroke rate. They were instructed to perform their usual rowing technique, especially in terms of stroke length, over a 250m distance.

A single scull was instrumented to measure the external forces generated by the rower at the pins (the force transferred from the oar through the oarlock, Smith and Loschner, 2002) and at the foot stretcher. A new foot stretcher was constructed using two carbon fibre composite core 'sandwich' sheets (Divinycell H, DIAB International AB) each fitted with three force transducers (Model 9602A, Kistler Instrument Corp., AG Winterthur, Switzerland) to record 3D reaction forces under the feet. Angular velocity was collected using a three dimensional gyroscope (Analog Devices ADXRS300 Gyroscope) and, after integration, was used to measure the angular pitch (about the horizontal axis), roll (about the longitudinal axis) and yaw (about the vertical axis) of the boat.
Data were collected using a high quality telemetry system (ROWBOT, Digital Effects, Australia) at a sampling rate of 100Hz and transmitted to a laptop computer (4700CT, Toshiba). Data were analysed using a custom designed integrated software program written in Visual Basic and a 10Hz zero phase-shift Butterworth filter used to smooth the data. Twelve full strokes were analysed from each 250m rowing trial. Strokes were defined by the minimum oar angle (catch angle) signalling both the start and end of the rowing stroke, and the maximum oar angle (release angle) determining the end of the drive phase and the start

of the recovery phase. Each stroke was time normalised to 100% stroke. All 12 strokes were used to form an average stroke profile for each rower, and then ensemble averaged to indicate variability across subjects.
The pitch of the boat was measured as changes in the vertical displacement of the bow of the boat, in cm, from a horizontal axis through the middle of the boat. Roll was measured as vertical displacement of the oarlock pin about the longitudinal axis of the boat. To be consistent with common rowing terminology, stroke side roll is reported as elevation of the right hand side of the boat when facing forward. Bow side roll is defined as elevation of the left hand side of the boat. Yaw of the boat was measured as the change in direction of the stern of the boat about the vertical axis of the boat, again reported in cm from the midline.

RESULTS AND DISCUSSION: The pitch of the boat alters by up to 3.5cm throughout the duration of the stroke. 'Bow up' pitch, where the bow of the boat moves up and the stern of the boat moves down, increases in the late recovery phase as vertical stretcher forces increase rapidly while the rower slides back towards the catch position (Figure 1). As the oar enters the water at the catch position, the rower applies propulsive forces at the handle and foot stretcher to accelerate the boat. At this point, the rower also pushes down on the foot stretcher, increasing the pitch of the boat.

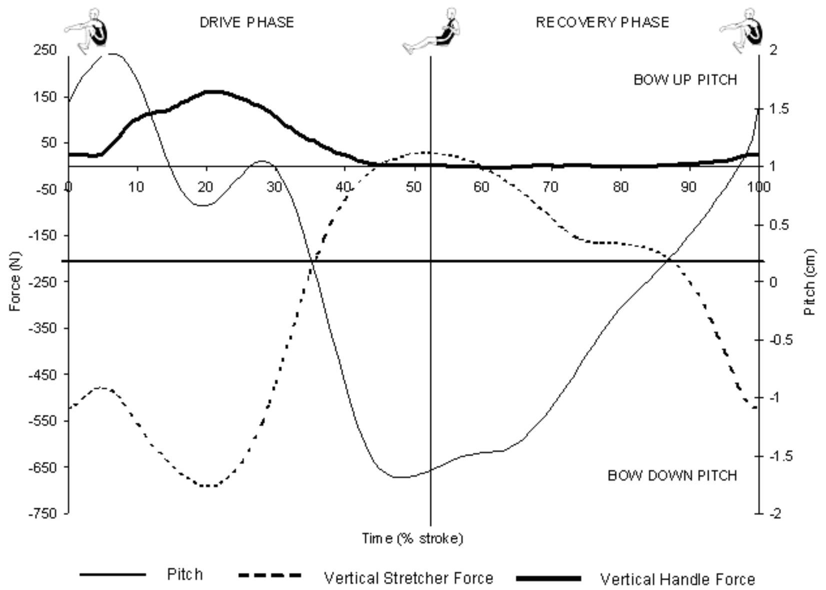

Figure 1: Vertical pin and stretcher forces and their effect upon the pitch of the boat.

Positive vertical forces on the pins also increase during the early part of the drive phase to ensure that the blade remains fully submerged in the water throughout the stroke. The coordinated increase of vertical pin forces and decrease of vertical stretcher force causes the 'bow up' pitch of the boat to reduce throughout the drive phase. Towards the end of the drive, the pitch of the boat changes to a 'bow down' orientation as the centre of mass of the rower moves further towards the bow of the boat. Extension of the trunk at the finish position increases the displacement of the centre of mass of the rower towards the bow of the boat, further increasing the 'bow down' pitch. At the finish position and through the early recovery phase, the vertical forces acting through the stretcher and pins are minimal, so it is the weight force of the rower acting through the seat that maintains the 'bow down' pitch of the boat. The 'bow down' pitch of the boat reduces as the rower initiates the slide back towards the catch. Vertical forces are increased rapidly at the stretcher as the rower moves forwards, so the 'bow up' pitch increases again approaching the catch. The investigation of these forces delivered through the seat has not been conducted in the present study. However, a better understanding of the relationship between the transfer of vertical forces between the stretcher, pin and seat would be of benefit to rowers and coaches due to the high ratio of the mass of the rower to that of the boat.

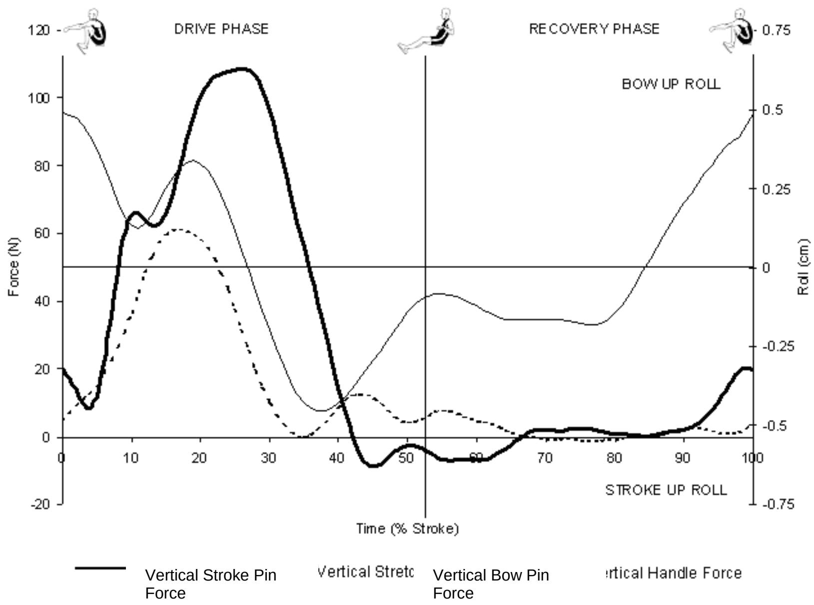

Figure 2: Vertical pin forces and their effect upon the roll of the boat.

While the total vertical forces acting upwards on the pin are coordinated with the forces at the stretcher to reduce the pitch of the boat, the forces applied at the individual bow and stroke side pins are uneven (Figure 2). Vertical forces generated at the bow side pin are of greater magnitude than those of the stroke side pin. This occurs because the gate on the bow side pin is positioned higher during the rigging set-up than that of the stroke side gate to enable the right hand to pass over the left when the oars draw through in the drive phase. Increased bow gate height introduces an asymmetrical aspect to the rowing stroke, suggested by Wagner et al (1993) to be a reason for the repetitive rolling and yawing of the boat. Caution should be used when viewing average roll curves because variance in the data results in the mean is not necessarily representing any given rower.

At the catch position, the vertical bow pin forces increase as the oar enters and is submerged in the water, causing the roll of the boat to increase on the bow side. 'Bow side' roll peaks at the catch position with an average value of 0.5 cm. As the drive phase begins, vertical force is generated at the stroke side pin which counteracts those produced at the bow side pin, reducing the bow side roll of the boat. Bow side roll is again elevated as the hands cross over each other in the mid drive phase, causing an increase in the vertical bow side pin forces and an increase in asymmetry within the stroke.

After the second peak of bow side roll, the boat 'rolls' to the stroke side, despite the vertical bow side pin force continuing to rise, and the stroke side pin force reducing. This may be due to a postural control mechanism employed by the rowers, who adjust the distribution of their weight force through the seat to maintain the balance of the boat and reduce the roll to one side. Once again, instrumentation of the seat to measure forces would enable analysis of the distribution of vertical forces through the seat to see whether coping mechanisms were being implemented by the rowers to maintain boat balance.

The stroke side roll reduces at the finish position, when the 'legs down' position of the stroke enables the rower to provide a stable base by which they can minimise fluctuations of boat movement and maximise the 'run of the boat' in the water (Mazzone, 1988). The roll remains relatively stable until the rower returns to the catch position.

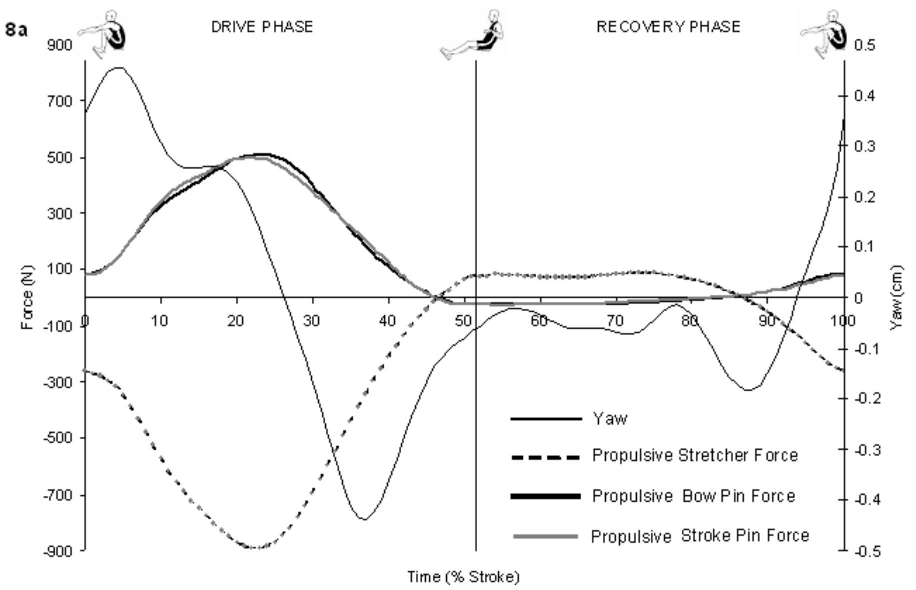

Figure 3: Propulsive pin and stretcher forces and their effect on the yaw of the boat.

Oscillations occur in the yaw of the boat during the late drive and early recovery phase (Figure 3). Changes in yaw of the boat were greatest during the drive phase when propulsive pin and stretcher forces were at their greatest. These oscillations may therefore occur as a result of unequal development of pin and stretcher forces. While the average peak displacement in figure 3 was 0.46 cm, four out of the eleven rowers yawed initially in the opposite direction, depending on the magnitude and timing of horizontal pin forces. The average amount of yaw (ignoring direction) was 1.2 cm. The synchronicity of foot stretcher force application would also have an effect upon the yaw of the boat if a rower delivered a larger proportion of the stretcher forces through one of the legs. Further instrumentation is required to measure this effect as the current study measured only a single force for both feet.

CONCLUSION: On average, boat orientation deviated from a neutral position by about 2 cm for pitch, 0.5 cm for roll and 0.3 cm for yaw. These orientations were greatest just after the catch of the stroke when large forces were applied to the foot stretcher and oarlock pins. These values were averages for the group, with some individuals producing much larger motions than this, and there being variation within each individual's set of strokes. Technology may allow feedback to be provided to rowers and coaches may be an effective way to train rowers to reduce fluctuations in boat orientation and therefore to reduce energy loss through hydrodynamic drag.

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