NET POWER PRODUCTION AND PERFORMANCE AT DIFFERENT STROKE RATES AND ABILITIES DURING PAIR-OAR ROWING

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Economy in propelling a rowing boat is important in competitive rowing as, for a given power output from the rower, the more effective the rower is the faster the boat will go for a given power output. Velocity cost (average power required to propel the boat for each m s^{-1}) is a measure that will discriminate between effective and ineffective rowers. The purpose of this study was to measure a number of capacity and technique variables (including velocity cost) during on-water rowing of paired boats at 20, 24, 28 and 30 str min^{-1}. Among the four pairs of rowers tested clear differences were found at particular boat velocities in the velocity cost. A number of technique variables were identified as possible causes of these differences. A linear regression analysis included six of these parameters which together explained 97% of the variability in velocity cost.

KEY WORDS: rowing, power, pair-oared boat, efficiency, effectiveness

INTRODUCTION: During on-water rowing, power developed by the rower may be delivered to the oars through the hands and to the foot stretcher through the feet. The proficiency of the rower will be partly determined by the effectiveness with which this power is coupled to boat propulsion. Sanderson and Martindale (1986) proposed that there were three components important to maximising boat velocity: extraction fo the maximum amount of power from the rower's body; use of as much of this power to propel the boat; and use this propulsive power in an efficient manner to move the boat at the greatest possible mean speed (p 454). Velocity cost, the ratio between the external power developed by the rower and the average velocity of the boat (the number of watts required to propel the boat for each m s^{-1}) is one effectiveness measure. Propulsion is defined as any action that directly affects the forward progression of the boat. For example, the transverse component of the handle force is a necessary accompaniment to the longitudinal component of the total handle force but has no effect on propulsion. The purpose of this paper was to develop the concept of velocity cost, measure it on-water with pair-oared boats and search for cause and effect links which explain the variability expected among rowers. Once these connections are found, they will comprise a useful tool for rowers and coaches in the improvement of rowing performance.

METHODS: Four male state level pairs rowed an instrumented pair boat at steady state cadences of 20, 24, 28, and 30 strokes per minute. Boat velocity was measured with a magnetic turbine and pickup coil, pin force with multi-component force transducers, stretcher forces with strain gauge transducers, and oar angles with servo potentiometers. The three-dimensional orientation of the boat was measured with gyroscopes. This information was sampled at 100 Hz and telemetered to a laptop computer on the shore. Approximately twenty strokes were time normalised and averaged at each stroke rate. Power delivered to the boat by the rowers was calculated as the product of boat velocity and pin or stretcher force. Power delivered to the oar handle was calculated as the product of the handle force and handle velocity. Handle velocity was the result of the angular velocity of the oar and linear velocity of the boat. To calculate the handle forces from the pin forces, the oar was modelled as a simple lever with the water acting as a fulcrum. Motion in the horizontal plane only was considered.

The powers associated with each rower were summed. Total power was then integrated over the stroke to obtain the total external energy generated by the rowers at the oar handles and stretchers. This energy was then divided by the time per stroke to provide the average power for that stroke rate. The work effectiveness for each pair of rowers was calculated by dividing the pair's energy output in a propulsive direction by the total energy spent.

RESULTS AND DISCUSSION: The mean height and weight of the rowers was 186.5 ± 0.8 cm and 89.6 ±1.4 kg respectively.
The patterns of power production involved both absorption and generation (Figure 1). During the drive phase the net propulsive power delivered by the pair was the balance between large amounts of power absorbed by the rower from the stretcher and high magnitudes developed at the stoke and bow oar handles. This balance is negative during the first 10% of the stroke then remains positive for the remainder of the drive phase. Towards the finish the propulsive power produced by the pair almost reaches zero but then climbs to a low positive level for the recovery phase up to 90% of the stroke. A small absorbing phase brings the net power up to the next catch. Although the rower experiences the greatest physiological stress during the drive phase, examination of the area under the net propulsive power curve (the energy) reveals that the net energy provided to the boat by the rower during the recovery phase is comparable to that of the drive phase.

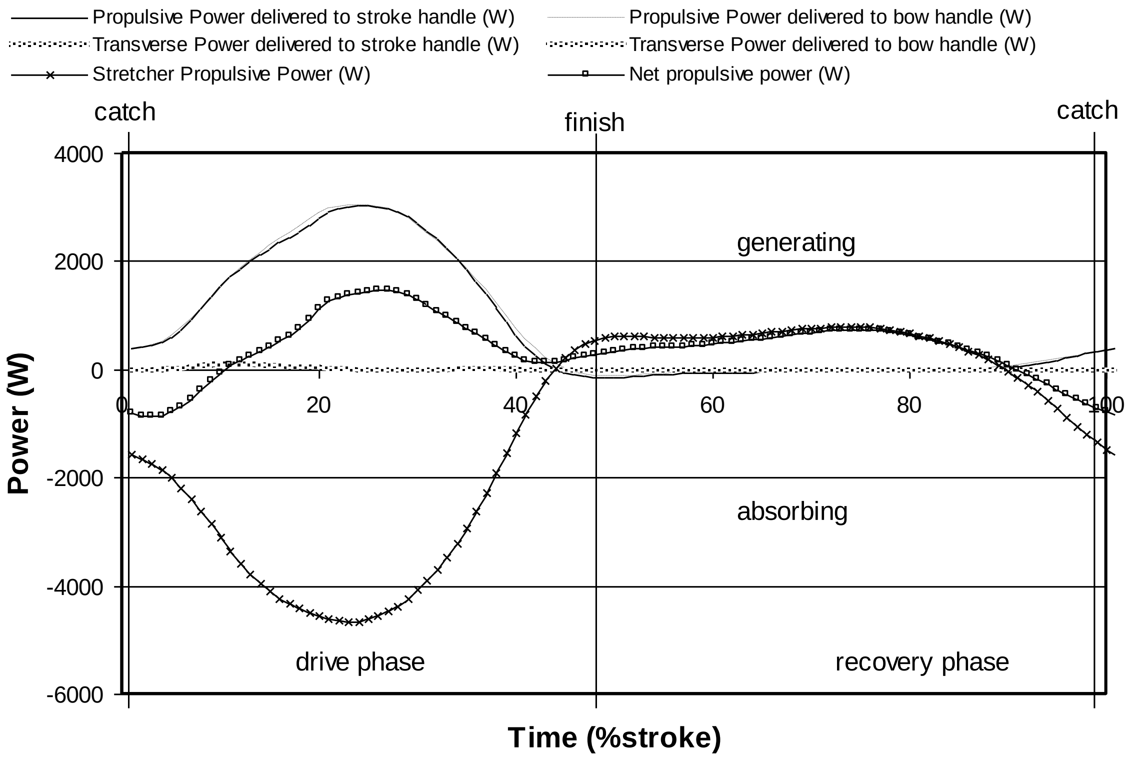

Figure 1 - Ensemble average pair power output time series at 30 strokes per minute.

The mechanical effectiveness of the rowers was described by the velocity cost: the power expended by the rowers in producing each metre per second of velocity. It is also equivalent to the energy expended in moving the boat each metre. All rowers were of similar mass and rowed the same pair boat. Thus, potentially, each pair would encounter the same drag at the same velocity. Differences in the drag could be caused by unbalanced application of force causing the boat to yaw, pitch or roll and present changing cross-sections to the water and creating different amounts of wave drag.
Since drag is proportional to velocity squared it could be expected that the velocity cost would increase with boat speed. This is evident in the results (Table 1). Among the pairs however there was considerable variability in this relationship. Although the general trend was for increasing average powers being required for higher boat velocities ($r = 0.80$, $p < 0.001$) for each pair there were considerable differences in the amount of rower average power output expended in producing boat velocity (Figure 2). This afforded an opportunity to

examine the reasons why pair A were able to attain different boat speeds for the same average power output (at 24 and 28 str min^{-1}). A further point of interest was why pair C used more average power to achieve the same boat velocity as pair A while both were rowing at the nominal 28 str min^{-1} level.

Table 1 Mean ±SD for the Actual Stroke Rate and Velocity Cost at the Four Nominal Stroke Rates

Stroke Rate (min^{-1})	Actual Stroke Rate (min^{-1})	Boat Velocity (m s^{-1})	Velocity Cost W/m s^{-1}
20	20.3 ±1.3	2.8 ±0.2	152 ±23
24	25.3 ±1.9	3.1 ±0.1	198 ±23
28	27.5 ±1.3	3.1 ±0.1	214 ±31
30	30 ±1.2	3.3 ±0.3	241 ±21

In the first case (pair A) exhibited differences in the phasing and magnitude of the stroke- and bow-side pin forces. This in turn led to a larger yaw magnitude at 28 str min^{-1} than at 24 str min^{-1}. This would lead to a larger drag and thus higher velocity cost for the rowers performance at 28 str min^{-1}.

In the second case both stroke- and bow-side seat velocity ranges were higher for pair C than pair A. If the rower centre of mass position could be modelled as the seat position, a higher seat velocity would imply a higher centre of mass velocity and thus more kinetic energy stored. The boat velocity also had a larger range for pair C than for pair A, and the power expended moving the handle transversely was larger making propulsion less efficient for pair C. Finally, there was an underlying imbalance in the power developed by the pair C. The ratio of stroke rower to bow rower power is usually within a few percent of one but the value for pair C was 0.86. To keep the boat moving in the correct direction, the rudder would have to be offset from the centre line thus increasing the drag. A steady offset such as this would not be detected by the yaw sensor whose frequency response is 0.2 – 20 Hz.

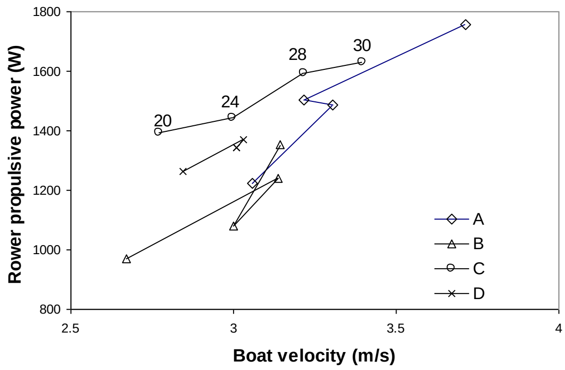

Figure 2 - The average propulsive power output required of each pair to produce the resulting velocities. Each curve begins at the laft with the data point for 20 str min^{-1} following the line for 24, 28 and 30 str min^{-1}.

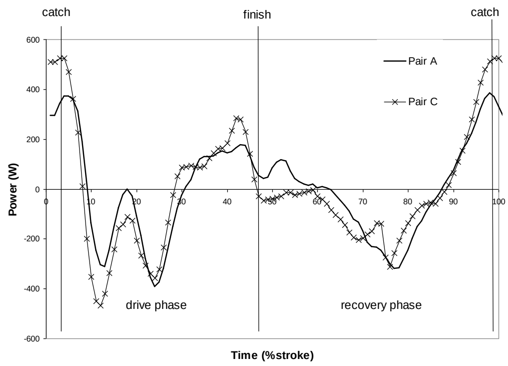

Figure 3 – The power associated with changing the trunk and thigh kinetic energy. The centre of mass of these segments is modelled by seat position.

This anecdotal evidence seems to suggest that the cause of ineffective rowing may be found in a number of variables: range of velocity for the seats and the boat, average power used to move the oar handle transversely, the range of boat yaw, pitch and roll, and the balance between the stroke and bow pin forces. A linear regression analysis (forward stepping) was carried out with velocity cost as the dependent variable. The first variable to be entered was boat velocity range ($p = 0.065$) then roll range ($p = 0.001$), average power to move the oar handle transversely ($p < 0.0001$), bow seat velocity range ($p = 0.006$),pitch range ($p = 0.0092$), stroke to bow propulsive pin force ratio ($p = 0.066$). The correlation coefficient was high at 0.99 ($p < 0.0001$).

CONCLUSION: The variable velocity cost gave a numerical value to the effectiveness of the pair rowers performance. Clear differences were shown among the rowers using this variable. The differences were associated with a number of technique variables. Linear regression analysis used most of these in producing an equation which was able to explain 97% of the variance in velocity cost.

The data collection and analysis was carried out with just four pairs of rowers at four different stroke rates. Much larger numbers must be found and measured at predetermined boat velocities before the researchers can make valid extrapolations to the wider rowing community.

The velocity cost (for a given boat and boat velocity) is a single number which can alert the rower or coach to the effectiveness of the performance. Once a problem has been identified, the cause(s) can be sought out in a number of technique-related parameters.

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