THE CONSISTENCY OF FORCE AND MOVEMENT VARIABLES AS AN INDICATOR OF ROWING PERFORMANCE

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A portable biomechanical collection system was used to test fourteen male, coxless pair rowing crews under simulated race speeds. The data was used to examine if the consistency of 8 biomechanical variables, calculated using a modified Coefficient of Variation (CoV), were related to the overall performance, in terms of velocity, of the crews. It was found that 6 of the variables demonstrated a significant correlation to overall boat speed, with the consistency of Normal Gate Force (r=0.737), Handle Velocity (r=0.758) and Trunk Velocity (r=.757) showing very strong correlation. It was concluded that while not imperative to the outcome, consistency of force application and movement patterns may be important in rowing performance.

KEYWORDS: rowing, force, consistency, movement

INTRODUCTION: In an effort to gain a better understanding of performance outcomes in the sport of rowing, researchers have steadily looked beyond the variables able to be derived through the examination of force production and related factors such as work and power. Whilst acknowledging that these factors have a large influence on performance, it has increasingly been realised that certain other mechanisms within the rowing stroke may be used in an effort to discriminate between skill levels (Dal Monte and Komor, 1988).
The notion of consistency of output has been examined as a discriminator in several studies. Smith and Spinks (1995) examined several work output and skill based variables derived from an ergometer test, in an effort to discriminate between subjects of different rowing ability, with stroke-to-stroke consistency of the handle force being found to be a significant indicator of classification. In a similar on-water study, it was again found that the consistency of force production was an important variable for discriminating between competition levels (Smith et al., 1994).
To further investigate this method as a potential discriminator of performance it was decided to extend the scope of the consistency quantification from the singular force applied to the handle, to an examination of four relevant force variables and four movement variables. The forces examined were the two forces measured at the gate, being those normal and transverse to the face of the gate, and the horizontal force applied to the left and right sides of the foot stretcher. The movement variables examined were the velocities of the 3 main components of the rowing stroke, namely the seat velocity, which equates to speed of leg drive, the trunk extension/flexion velocity measured as relative speed of C7 to the seat, and the velocity of the arms. A final movement variable was also included, being the handle velocity, which may be considered the overall product of the combination of the 3 previous components.

METHOD: The participants in this study consisted of 7 lightweight and 7 heavyweight male, coxless pair crews. The mean height and weight of the rowers was 187.1 ± 6.2 cm and 81.7 ± 10.3 kg respectively. All participants were currently training with an Australian sports institute and data collection was carried out as part of routine biomechanical testing. Each crew were tested whilst rowing in their preferred boat, which was equipped with a portable biomechanical data collection system. The system utilised purpose designed force transducers contained within specially designed gates and foot stretchers which enabled the

measurement of two-dimensional gate force and the horizontal force applied to the left and right sides of the foot stretcher.
Linear displacement of the moving seat and approximate position of C7 was also collected using drum and reel potentiometer transducers, similar to those previously used (Kleshnev, 2000; Smith and Loschner, 2002). The location of C7 was used to determine the position of the top of each athlete's trunk in reference to relative seat movement, providing an indication of trunk flexion and extension throughout the stroke. It is a limitation of the study that trunk movement could not be measured more precisely. Velocity of the arms was calculated as the difference in velocity between the oar handle and the C7 point. A similar arrangement has previously been used to estimate the proportion of segmental contributions to overall velocity and power (Kleshnev, 2000). Boat velocity and acceleration were determined by a Rover unit (James et al., 2004), which utilised a 100 Hz accelerometer coupled with a 1 Hz GPS receiver to determine instantaneous boat velocity. All data were sampled at 100 Hz and transmitted via radio telemetry to a receiver attached to a laptop via USB. Data was collected to hard drive as testing progressed, and was displayed on the laptop screen as numerical values for all the variables.
Prior to data collection, each crew was required to perform a pre-race warm-up to their satisfaction, followed by a step rate piece over a 2000m rowing course. At the completion of the 2000 m the participants were then required to return to the start of the last 500 m of the rowing course and, when they felt prepared, perform one 500 m trial at a full race effort, during which data was collected for this investigation. Athletes were instructed to perform the 500m at what they would consider their "mid-race" tempo and speed.
Post collection, 15 consecutive stokes were selected from each trial piece for further examination. This is a common method of obtaining representative ensemble data in biomechanical testing of rowing (Smith and Draper, 2006). The strokes were separated into single strokes using the position of zero degrees of the strokes oar during recovery, i.e., when the oar was perpendicular to the long axis of the boat. Each stroke was then time normalised to 101 points and variability of each parameter was calculated using a modified version of the Coefficient of Variation (CoV). The calculation of the modified CoV is shown, and expressed as a percentage, with 100 % representing repeated curves which are identical.

$$CoV = 100 \cdot \left(1 - \frac{\sqrt{\frac{1}{n}\sum \sigma_i^2}}{\frac{1}{n}\sum |X_i|} \right)$$

where:
n = number of intervals in the cycle
σ_i = st. dev. of variable X at ith interval
X_i = mean of variable at ith interval

Signal filtering was applied only to those variables that would be used to derive secondary variables (i.e. oar angle deriving oar speed) in order to minimise the introduction of noise due to differentiation. The cut-off frequency applied to the Butterworth low pass filter was determined by plotting the filter residual error versus the smoothing frequency (Winter, 1990) over a range of cut-off frequencies.
Bivariate correlations were performed to establish the relationship between the primary performance indicator of average boat velocity and the CoV of the four force and four movement variables. Level of significance was set at 0.05.

RESULTS AND DISCUSSION: The mean stroke rate of the race piece was 33.8 ± 1.0 strokes per minute. Results of the bivariate correlations are presented in Table 1.

Table 1. Calculated CoV of biomechanical variables and correlations to average boat velocity

		Normal gate force	Transverse gate force	Left stretcher force	Right stretcher force	Seat Velocity	Handle Velocity	Arm Velocity	Trunk Velocity
CoV(S.D.)		90.4(2.5)	84.4(3.9)	82.3(4.8)	83.8(5.0)	91.7(2.1)	94.4(1.3)	88.5(2.5)	90.9(2.2)
Average velocity	r	0.737**	0.578*	0.429	0.402	.599*	.758**	.633*	.757**
	Sig	0.004	0.038	0.144	0.174	.031	.003	.020	.003

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Examination of the correlations demonstrated that there was a significant correlation between the CoV of both normal gate force ($r = 0.737$, $p<0.01$) and transverse gate force ($r = 0.578$, $p<0.05$) to the average velocity of the boat. As the value of CoV can be affected by the magnitude of the mean value of the variable, and it has been previously shown that applied force may also be a good indicator of boat velocity (Leighton, 1983), it was necessary to conduct partial correlations between the variability of forces and boat speed, controlling for mean values of the force, the outcome of which are shown in Table 2

Table 2. Partial correlation matrix of variability controlling for mean force

		Normal gate force	Transverse gate force	Left stretcher force	Right stretcher force
Average velocity	r	0.649*	0.602*	0.454	0.114
	Sig	0.023	0.038	0.138	0.725

* Correlation is significant at the 0.05 level (2-tailed).

After taking into account the magnitude of the relevant forces it can be seen that the CoV of the force applied in a direction normal to the gate still exhibits a significant relationship to average velocity ($r=0.649$, $p<0.05$), as does that of the transverse force, or outward force applied along the long axis of the oar ($r=0.602$, $p<0.05$). Conversely there was no significant relationship found between the CoV of either the left or right foot stretcher force to the performance outcome of the boat.

The higher degree of variability of force applied to the foot stretcher may be attributed to a number of factors involved in the dynamics of rowing. During the recovery phase the only contact the athlete has with the boat is through the seat and foot stretcher. The recovery is also the least stable part of the stroke, with change in boat orientation, particularly roll of the boat, generally more noticeable (Loschner et al., 2000). While many athletes use the height of the oar handle during the recovery to stabilise this movement, some degree of balance is obtained through the adjustment of pressure on the feet. This must be performed while the seat is moving towards the stern, where force on the stretcher is used to halt momentum of the body in the latter stages of recovery. This effect is compounded in a crew boat, in which the rower is not only reacting to boat orientation but also the movement of his partner. It appears that while force on either foot is quite variable through the stroke, by the time the kinetic chain of the body is involved to transfer force developed at the stretcher to the handle, the variability in force is greatly reduced.

All four of the movement variables demonstrated a significant relationship to boat velocity, with the CoV of both the handle and trunk velocity exhibiting a correlation at the $p<0.01$ level ($r = 0.758$ and 0.757 respectively). The variability in arm velocity had a relationship of $r = 0.633$ ($p = 0.020$) and that of seat velocity $r = 0.599$ ($p = 0.031$). These results suggest that the manner in which crews perform the gross movement patterns within their technique may have a relationship to performance, in that those crews that more consistently repeated the same movement pattern stroke after stroke tended to exhibit higher average boat velocity over the same period. This may simply be due to the fact that the faster crews were more

proficient at performing these tasks, however, the crews were all of a similar standard in terms of rowing experience.
It appears that for this sample, the consistency of applied gate may be used as a discriminator in the prediction of performance outcome. This observation was extended to include a number of other variables, as significant correlation occurred between the major variable related to performance, that of average boat velocity, and the variability of forces applied to both the face and side of the gate, as well as the consistency of all 4 of the movement variables examined.

CONCLUSIONS

It appears that the use of variability of biomechanical variables in rowing may be of some use in predicting performance outcome. There was shown to be a significant relationship between the low variability in the force applied both normally and transversely to the face of the gate and the performance outcome of boat velocity. No significant relationship was evident for the foot stretcher force or within either the lightweights or heavyweights when treated as separate groups.
A similar trend was found when examining the consistency of the four selected movement variables of seat, body, trunk and handle velocity. Crews who exhibited a lower variability in these variables also tended to exhibit a higher average boat velocity. It is difficult to determine if reduced variation in these factors has a direct implication on performance outcome or, as outlined by Smith and Spinks (1995), are merely identifying better 'skilled' crews who also happen to be inherently faster.

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