DIFFERENCES IN BOAT VELOCITY RELATED TO TECHNICAL EFFICIENCY IN HIGHLY-TRAINED ROWERS

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Boat velocity is determined by both physical capacity and technical ability. By adjusting for power, we quantified differences in velocity attributable to technical efficiency. Stroke data from 47 2000 m races in male and female single sculls (10 and 8 boats) and coxless pairs (3 and 6 boats) were collected using Peach PowerLine and OptimEye S5 GPS equipment attached to boats. The logarithm of velocity was predicted with the logarithm of the sum of mean stroke power of both oars in a general linear mixed model for each boat class, a random effect for boat identity estimated a coefficient of variation representing differences in efficiency between boats. The differences were very large to extremely large (CV of 1.3-3.4%). Performance of boats with poor efficiency could be enhanced by improving technique, improving power output could be the focus for those with good efficiency.

KEYWORDS: rowing technique

INTRODUCTION: Rowing is a sport with high technical demand. An athlete's on-water performance ability is a product not only of their physiological work capacity but also their technical efficiency. Technical efficiency describes the ability to transfer work to the water while reducing energy losses and resistive drag forces in order to efficiently increase forward propulsion of the boat. Correspondingly, the overall efficiency of rower-boat system has been estimated between 17-20% (Hofmijster et al., 2009; Kleshnev, 2007). Although physiological efficiency is estimated to explain the majority (~77.2%) of these energy losses in the system, the remainder (~6%) comprises energy losses resultant of technical elements of the rowing stroke not related to stroke rate (Hofmijster et al., 2009; Kleshnev, 2007). This warrants consideration of the impact technical efficiency has on overall rowing performance.

The relationship between power output and boat velocity in rowing has revealed power to be proportional to boat velocity, with the exponent for velocity ranging from 2.6 to 3.2 for individual coxless pair boats (Hill & Fahrig, 2009). This demonstrates the variability in rowing technical efficiency between crews, whereby the resultant boat velocity for a given power output can be expected to differ between crews. However, the magnitude of between-crew differences in boat velocity when power is constant is not currently known.

Therefore, the purpose of this study was to use the relationship between power output and boat velocity to investigate differences in boat velocity related to technical efficiency. This was assessed as the differences in velocity when controlling for power output between-crews in male and female highly trained rowers during 2000 m racing in single scull and coxless pair boat classes.

METHODS: Fourteen heavyweight male (age 22 ± 3 y, mean ± SD; height 189 ± 8 cm; body mass 85 ± 10 kg) and 17 heavyweight female (age 21 ± 2 y; height 177 ± 6 cm; body mass 74 ± 8 kg) highly-trained rowers volunteered for this study, which was approved by the Victoria University Human Research Ethics Committee.

Data collection occurred during two national regattas held at the Sydney International Rowing Centre in February and March 2019. Participants performed 2000 m races in either single sculls or coxless pair boats from which power output from each stroke was collected with

Peach PowerLine instrumentation systems (Peach Innovations, Cambridge, UK) which has a sample frequency of 50 Hz. Boat velocity was collected with OptimEye S5 GPS units (Catapult, Australia) attached to participant boats. Venue environmental conditions (collected at 1-min intervals from six weather stations positioned at water level along the 2000 m course) were: 23.5 ± 3.2 °C air temperature (mean ± SD); 26.6 ± 2.1 °C water temperature; 58 ± 17 % relative humidity; and 1.4 ± 0.8 m/s wind speed, in a predominantly tail direction on bow side.

Calibration of Peach devices was performed immediately prior to each 2000 m race and involved zeroing force and angle measures. Set-up and calibration of the Peach system was done in accordance with manufacturer's instructions.

A total of 47 races was analysed, recorded from 17 singles and 8 coxless pairs. Each gender and boat class was analysed separately with the general linear mixed-model procedure (Proc Mixed) in the Studio University edition of the Statistical Analysis System (version 9.4, SAS Institute, Cary NC). In initial analyses, mean stroke power was predicted with a kinetic model consisting of additive terms for velocity cubed, change in kinetic energy from the previous stroke, and power developed against wind resistance. Contributions to predicted power of the terms for kinetic energy and wind were mostly trivial, so a simpler and more practical linear mixed model was used, in which the logarithm of boat velocity (V) was predicted by the logarithm of mean stroke power (P), allowing estimation of k and x in the kinetic equation $V = k.P^x$. The fixed effect log(P) adjusted log(V) for power output. Random effects were: crew identity (representing consistently better or worse technical efficiency of each crew across races), date identity (representing consistent effects of environmental conditions on each date), race identity within date (representing consistent differences in the effect of environmental conditions on a given date), and a different residual error for each crew (representing stroke-to-stroke variability in velocity not accounted for by the other effects).

A smallest important change in velocity of 0.3% was assumed, given the 1.0% race-to-race variation in 2000 m race times of elite rowers (Smith & Hopkins, 2011). Corresponding magnitude thresholds for coefficients of variation (CV) were: ≤0.15% trivial, >0.15% small, >0.45% moderate, >0.8% large, >1.25% very large, and >2.0% extremely large (Hopkins et al., 2009). Qualitative chances of CV being substantial were assessed as: 25-75% possibly, 75-95% likely, 95-99% very likely, >99% most likely. If the chance of the CV being negative and positive was >5%, the CV was deemed unclear.

RESULTS: The exponents in the kinetic equation $V = k.P^x$ (for which the theoretical value is 0.33) for the male and female single sculls were both 0.36 (90% compatibility limits ±0.01), while those for coxless pairs were 0.38 (±0.01) for males and 0.37 (±0.01) for females. The effects of environmental variation on boat velocity represented by the random effects for date and race identity ranged from moderate to very large, but all were unclear. Residual errors representing the stroke-to-stroke variability in within-crew boat velocity expressed as CV ranged from 1.3% through 4.1% (90%CL ~±0.2%) across all boat classes and crews. Individual crew residual errors are presented in Table 2 for the Women's singles boat class.

The random effect for crew identity provided the between-crew differences in mean velocity for a given power output are presented in Table 1. There were clear extremely large differences between single-scull crews. Differences between the coxless-pair crews were very large (men's) and extremely large (women's), but with less data for this boat class, the differences were unclear.

Table 1. Mean stroke power and mean boat velocity in four boat classes, and between-crew differences in mean velocity when power is statistically held constant.

Boat class (n,m)	Mean stroke power (W)	Mean boat velocity (m/s)	Between-crew differences (CV, ±90% CL)
Men's single scull (10,17)	334	4.60	3.3, ±1.7*
Men’s coxless pair (3,5)	760	4.97	1.3, ±1.8
Women’s single scull (8,13)	223	4.14	2.5, ±1.5*
Women’s coxless pair (6,12)	481	4.33	3.4, ±2.8

n, number of boats; m, total number of races; CV, coefficient of variation; CL, compatibility limits.
*clear extremely large differences, very likely substantial.

Table 2. Individual-crew differences from group mean boat velocity in Women’s singles when power is statistically held constant (summarized by the CV in Table 1), and stroke-to-stroke variability in velocity.

Crew ID	Velocity difference from group mean, ±90% CL (%)	Stroke-to-stroke variability in velocity (CV, ±90% CL)
A	4.1, ±2.0	1.4, ±0.1
B	2.2, ±2.7	1.3, ±0.1
C	0.3, ±2.2	1.5, ±0.1
D	0.3, ±2.0	1.5, ±0.1
E	-0.6, ±2.1	2.3, ±0.2
F	-1.2, ±2.0	2.0, ±0.1
G	-1.4, ±2.2	1.8, ±0.1
H	-3.6, ±2.0	2.4, ±0.1

DISCUSSION: The differences in velocity between crews after adjustment for power output (as shown in Table 1) likely reflect differences in technical efficiency. Larger energy losses in the rower-boat system can be expected to occur in crews where lower boat velocities are achieved for the same power output, whereby a smaller portion of the power measured at the oarlock is translated into forward propulsion of the boat.

The random-effect solution for crew identity provided estimates of the relative different efficiencies of each crew (as presented in Table 2) for the Women’s single boat class. Consistent differences in wind and other environmental conditions between races were adjusted for and would therefore not contribute to the differences between crews. However, differences between crews in variables such as the rower-boat system mass, hull surface area, and oar blade design may have contributed to these differences and should be considered.

The stroke-to-stroke variability in boat velocity differed between crews and can be expected to some extent reflect differences in rowing technique between strokes. The variability may reflect changes in technical focus during the race (it is not uncommon for race strategies in rowing to include pieces with specific technical foci), rower fatigue in the later part of races resulting in a compromised ability to maintain preferred rowing technique, or the effect of abrupt changes in pacing increasing the drag acting on the boat with variations to boat velocity (Brearley et al., 1998). Within-race changes in environmental conditions such as wind gusts cannot be adjusted for with our kinetic model and may have also contributed to the within-crew variability reported.

Reducing within-crew variability in boat velocity for a given power output appears to be advantageous to rowing performance. The tendency observed for less variability of within-crew velocity to be associated with more technically efficient crews (larger positive deviations from the group mean boat velocity, as shown in Table 2 for Women's singles) may also relate to better overall rowing performance. However, further investigation of the relationship between the variability of within-crew velocity and crew technical efficiency with 2000 m race time is needed. Nevertheless, the authors' observations correspond with associations reported between improved boat velocity and reductions to within-stroke boat velocity fluctuations (Hill & Fahrig, 2009; Liu et al., 2018).

CONCLUSION: In conclusion we have found substantial differences between crews in estimates of technical efficiency and the variability of within-crew boat velocity, with an association observed between these measures. Performance of crews with poor efficiency could be enhanced by improving technique, while improving power output could be the focus for those with good efficiency. Further modelling that includes measures taken from the oar and boat instrumentation may reveal the extent to which rowing technique explains differences and variability in boat velocity.

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