PADDLE MECHANICS DIFFER BETWEEN ON-WATER AND ERGOMETER SPRINT KAYAKING

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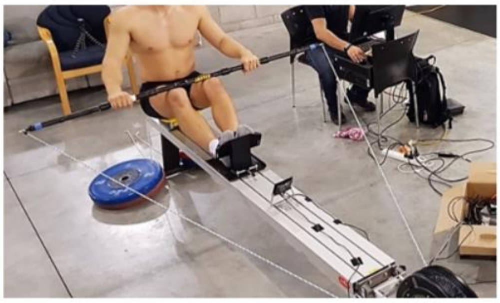
This study investigated biomechanical differences between on-water and ergometer kayaking using a custom sensor-equipped paddle. Five elite male kayak sprint athletes performed identical kayak-specific incremental paddle protocols ranging from stroke rate (SR) 30-90 strokes/min on a kayak ergometer and their typical training venue. Sensor paddles and GPS units were used to collect paddle kinetics and boat motion, respectively. Large to very large differences were observed for pull time (T_{pull}) (d = 5.9 ± 0.39), air time (T_{air}) (d = 3.7 ± 0.27), mean force (F_{mean}) (d = 1.06 ± 0.19), peak force (F_{peak}) (d = 1.92 ± 0.22), impulse (d = 2.62 ± 0.23), and impulse rate (IR) (d = 2.10 ± 0.21) between environments. Mixed-effects models and Statistical parametric mapping (SPM) analysis revealed variable differences across intensity levels. These results reveal substantial dissimilarities of paddle kinematics and kinetics between ergometer and on-water kayaking.

KEYWORDS: KAYAK, CANOE, PADDLE, KINETICS

INTRODUCTION: Ergometers are widely popular in paddle sports for testing and training; however, their task specificity is unclear. While many have identified the value of reliable and valid machines for these purposes (Begon et al., 2008; von Someren et al., 2000), studies have identified physiological and mechanical differences for kayakers between ergometer and on-water paddling (Fleming, Donne, Fletcher, et al., 2012; Villarino-Cabezas et al., 2013). Athletes performing maximal testing on ergometers express higher stroke rates (SR), elbow movement velocity, and anterior deltoid EMG activity (Fleming, Donne, & Fletcher, 2012; Klitgaard et al., 2020). Conversely, Fleming, Donne, Fletcher, et al. (2012) found significant differences in rate of force development, but not other variables.
Recent developments in sensor technology have aided researchers in evaluating kayak biomechanics in diverse ways. Klitgaard et al. (2020) used an inertial motion capture system to demonstrate differences in elbow, shoulder, and trunk kinematics between on-water and ergometer paddling. Custom and commercially available (One Giant Leap, Nelson, NZ) instrumented paddle setups have enriched knowledge regarding on-water kayak biomechanics, providing normative data on elite paddlers and key performance indicators (Gomes et al., 2011; Macdermid & Fink, 2017; Tullis et al., 2018). These tools are not only valuable for training and testing but could be used to compare paddling biomechanics between individuals and environments. To our knowledge this has not been examined in the literature. Thus, the current study sought to compare ergometer and on-water kayaking in elite athletes using a custom sensor paddle.

METHODS: Five healthy male athletes (age 20±2.1 y, height 181.4±4.6 cm, weight 86.9±7.0 kg) from the Canoe Racing NZ high performance squad participated in this study. Indoor (ergo) and outdoor (H2O) testing was performed on the same day, with approximately 10h between trials. Both experimental protocols were identical: after a standardised warmup, athletes were instructed to paddle at six increasing intensities according to their prescribed training zones (Table 1). These zones were regulated by asking athletes to paddle at specific SR to replicate those used in their typical training, plus a maximal exertion trial of 15s. Preliminary data showed the athletes to be highly reproducible in following each SR (expressed as right + left combined) as used in daily trainings, and they were instructed to replicate the SR, technique, and feel as closely as possible across test levels in both environments.



Level	SR (R+L)	Duration
Warmup	20-30	10:00
1	32	3:00
2	36	2:00
3	40	1:00
4	48	1:00
5	60	:30
6	~	:15

Figure 1. (a) Ergometer setup with smart paddle (b) Experimental protocol. SR=stroke rate, combined right and left.

Indoor testing was performed on the same Dansprint (DS) ergometer which was calibrated to factory recommendations and used for all testings. The KZ2 smart paddle (SP) is a custom setup manufactured by Goldmine (HPSNZ, Auckland, NZ) from a Jantex carbon shaft (Banka, Slovakia), strain gauge arrays (256 Hz), and an IMU (100 Hz). The SP was first calibrated via a first-principles device, with excellent comparative reliability (ICCs≥0.90) versus the DS in SR, T_{pull}, and power. One SP was used for ergometer testing, and each athlete used a SP shaft calibrated, measured, and fitted with their own respective blades for H2O testing. Footrest distance was individualized and match between environments. Windbot and Tidebot (Igtimi, Dunedin, NZ) devices were used to monitor wind and current, respectively, which were both negligible.

SP data were analysed using HPSNZ logger software (MATLAB runtime 9.4 [MathWorks, Matick, USA]) to extract continuous and discrete variables including SR, T_{pull}, T_{air}, F_{mean}, F_{peak}, and the product of impulse and SR, “impulse rate” (IR) as a surrogate of work rate. Statistical analyses were done using XLSTAT (Addinsoft, Paris, France), Tableau (Tableau, Seattle, USA), and Stata (Statacorp, College Station, USA). Cohen’s D effect sizes, linear and nonlinear regression were used to determine the differences between environments according to test level and SR. Regressions were compared via a mixed models approach controlling for SR and athlete. SPM was used to determine the existence of statistically significant differences in force-time profiles at each test level (Penny et al., 2011).

RESULTS: Ergo and H2O paddling had significant differences in kinematic variables across all intensities. Pooled group data was visualised on scatterplots with SR as the independent variable (Figure 2). T_{pull} decreased progressively as SR increased for both conditions; however, ergometer paddling had a consistently lower T_{pull} even when controlling for SR (slope difference = -0.160±0.00, SE=0.001, z=-152.52, d=4.62-6.2, p<0.01). T_{air} also decreased as SR increased; in contrast, ergo paddling had consistently longer T_{air} compared to H2O paddling (slope difference=0.42 ± 0.01, SE=0.003, z=152.82, d=1.07-5.32, p<0.01). F_{peak} and F_{mean} were increasingly different as the intensity level increased. The greatest difference between the variables was observed at maximal intensity, following a curvilinear relationship as SR increased (Figure 2). F_{peak} showed the greatest difference between environments, with the difference increasing at higher intensities (slope difference=28.72±1.74, SE=0.89, z=32.28, p<0.01).

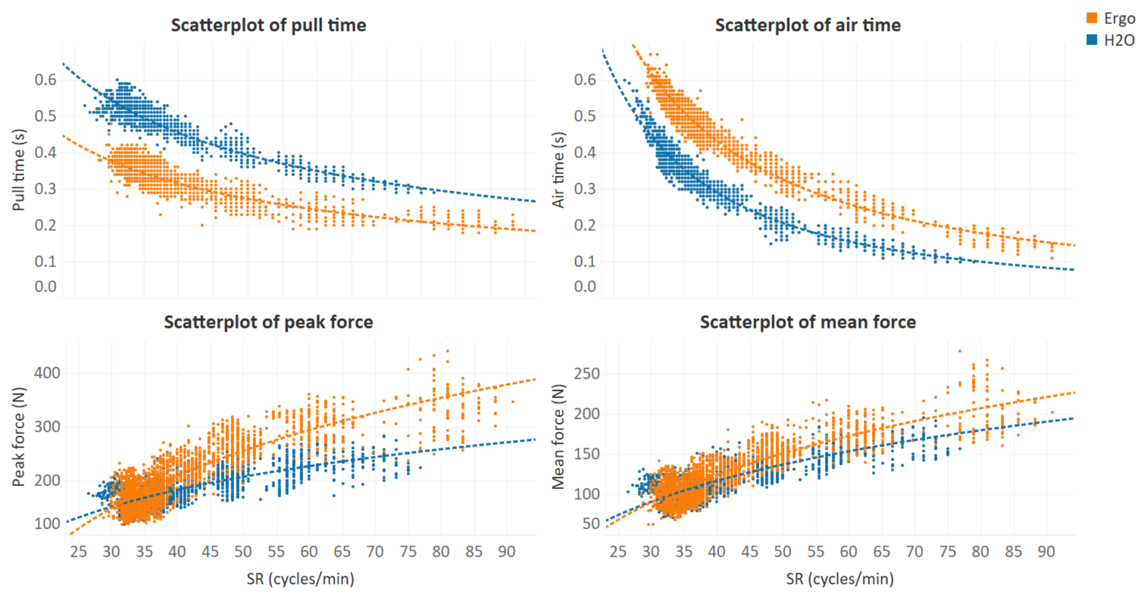


Figure 2: Scatterplots of all strokes show T_{pull}, T_{air}, F_{peak}, and F_{mean} differences and trends across stroke rates for ergometer and on-water paddling

Examination of the time normalised averaged force-time profiles revealed clear differences in magnitude and shape across all intensities. SPM determined that blade force was significantly higher in the ergometer condition during early pull (start to 34%) at the lowest intensity level ($t=2.64$, $p<0.001$). Differences were greater and shifted as intensity increased (Figure 3).

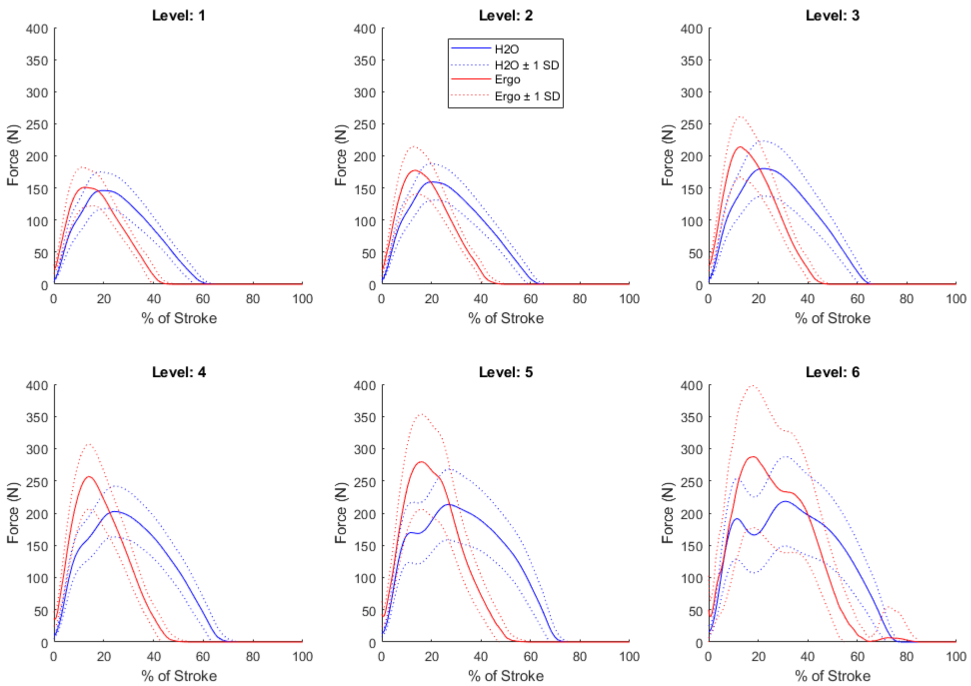


Figure 3: Normalised force-time profiles for all participants across ergometer and on-water trials

DISCUSSION: Large, significant differences in kinematic and kinetic variables between environments indicate that the task specificity of ergometer paddling is low. Regression analyses indicated that differences in T_{pull}, T_{air}, F_{peak}, F_{mean}, and IR occur across most tested intensities. The SPM analysis located meaningful differences in force-time profiles between environments, and were greater at higher intensities.

Although some ergometer performance profiling is performed at submaximal levels, maximal intensities are frequently tested by researchers, coaches, and athletes. These data are especially important in this context. Large, significant differences in kinematic and kinetic outputs (e.g., F_{peak} d=2.74±0.37, p<0.01) are maximised at the highest intensity levels (Table 3). Athletes were able to achieve higher SRs on the ergometer due to significantly shorter T_{pull}. Despite the short pull phase, much higher F_{peak} was observed during ergometer paddling. These higher forces may be attributed to differences between flywheel resistance and paddle drag, and their impact on the ability of the athlete to produce force. Ultimately, the small difference in IR between environments summarises one of the most important conclusions: at maximal intensities, athletes produce practically equal work on the ergo and H2O. A possible cause of this has been proposed by Fleming, Donne, Fletcher, et al., 2012 who suggested the observed kinetic differences might be explained by elastic rope tension and manifest as altered shoulder and trunk muscle activation. Although increased forces are seen on the ergometer, the beneficial or potential detrimental effects have not been investigated.

Table 3. Group means and effect sizes for biomechanical variables of ergometer and on-water paddling at maximal intensity

	SR		T_{Pull}		F_{Peak}		IR	
	Ergo	**H2O**	**Ergo**	**H2O**	**Ergo**	**H2O**	**Ergo**	**H2O**
Mean	80.4	68.2	0.21	0.32	333.5	233.9	112.0	115.6
d	2.06±0.33**		6.20±0.65**		2.74±0.37**		0.28±0.27**	

*Notes. d=effect size, ** p<0.01.*

CONCLUSION: Elite athletes showed different paddling mechanics between ergometer and on-water kayaking. Coaches, staff, and athletes should exercise caution when using ergometer for extended training periods, or when interpreting test results.

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