FOOTBOARD AND SEAT KINETIC CHANGES ASSOCIATED WITH STROKE RATE ON A KAYAK ERGOMETER

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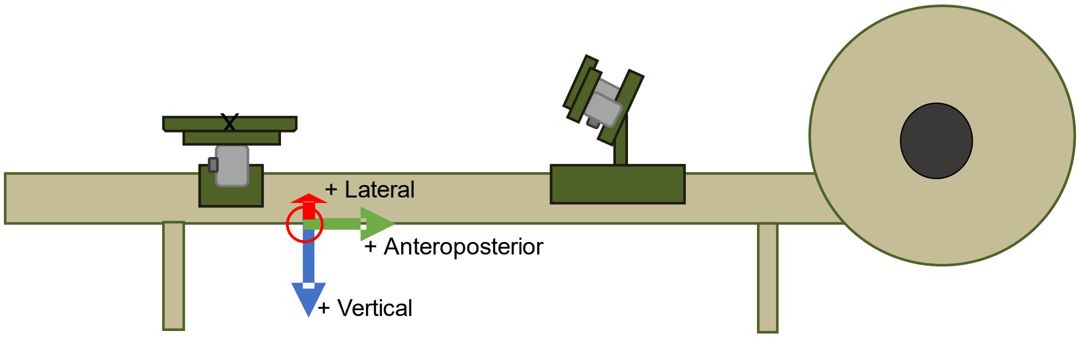
The purpose of this study was to determine if stroke rate effects anteroposterior, lateral, and vertical forces on the kayak's footboard and seat. Participants (n=10), with a year or more of competitive kayaking experience, completed four 30-second trials on a kayak ergometer at different stroke rates (60 strokes per minute (spm), 80 spm, 100 spm, and maximum spm). Mean force, impulse, and impulse*stroke rate were identified for the footboards, and seat, separately within each trial (ten single strokes). Interestingly, both anteroposterior and lateral axes kinetic adaptations to stroke rate occurred on the left footboard whereas the right footboard presented only lateral adaptations.

KEYWORDS: sprint kayaking, forces, stroke rate, kinetics, equipment

INTRODUCTION: Sprint kayaking requires highly coordinated and precise movements between the upper and lower body which result in time-specific force application. Kayakers generate force as they draw their paddle through the water (Michael et al., 2009). This force is transferred through the athlete's body and into the boat through the two points of contact: the seat and the footboard. Primarily, the propulsive forces originate from the upper body, but a 16% mean kayak speed and 21% mean paddle force decrease has been observed when the lower body is constrained (Nilsson and Rosdahl, 2016). For context, a 16% decrease in kayak speed could result in the addition of nearly 6 or 30 seconds in a 35 second or 4-minute race, respectively. Several studies have assessed a sprint kayaker's paddle forces (Michael et al., 2009), while only few have assessed the forces in the seat (Begon et al., 2009) and footboard (Nilsson and Rosdahl, 2016). Currently, the literature measuring seat and footboard forces have solely presented forces in the anteroposterior plane (i.e., the direction the kayak travels). Characterizing footboard and seat forces aids in the understanding of propulsive force production in sprint kayakers. No research has investigated whether SR alters the forces acting on the footboard or the seat. Therefore, the purpose of this study was to determine if stroke rate effects anteroposterior, lateral, and vertical forces on the seat and footboard.

METHODS: A Dansprint® paddling ergometer (Dansprint, ApS, Denmark) was instrumented with three AMTI AD2-5D load cells (AMTI Force and Motion, Watertown, MA): one for the left and right footboards, separately, and one for the seat. The footboard and seat load cells were instrumented and adjusted to participant's preferences, as per Bugeya Miller (2021). All data were collected at 1000 Hz. Ten participants (4 females, 20 ± 6 years, 72 ± 9 kg, 12 ± 5 years spent kayaking) of provincial to national team level were recruited. The ergometer fly-wheel drag was set as per Dansprint® recommendation and was based on the athlete's weight. Participants were asked to perform a 10-minute warm-up prior to completing four randomized 30-second SR trials at 60 strokes per minute (spm), 80 spm, 100 spm, and maximum (max) spm. Three-minutes of rest was given between trials. Participants were instructed to attempt to paddle with maximal effort without changing their technique (i.e., flicking the paddle during the exit phase). Forces were translated into the global coordinate system as per Bugeya Miller (2021) (Figure 1). A stroke cycle was defined as the initiation of the left footboard push to just before the initiation of the following left footboard push, where one stroke cycle included two footboard strokes. The footboard push was identified as anteroposterior footboard force zero-crossing, where positive anteroposterior footboard force was identified as pushing force and negative anteroposterior footboard force was identified as a pulling force. Ten stroke cycles were analyzed for each individual trial within the footboards and seat, separately, for each participant (ten stroke cycles × four trials per participant). Mean force, impulse, and impulse*SR discrete measures were identified for the individual components (anteroposterior, lateral, and vertical) of the resultant forces within each stroke cycle. For the 60 spm, 80 spm, and 100 spm trials the impulse was multiplied by the designated stroke rate for the impulse*stroke rate to calculate the approximate impulse per minute. For the max spm trials impulse*stroke rate variable, the impulses were multiplied by the individual participant's average stroke rate for that trial to calculate the approximate impulse per minute. The ten-stroke cycle discrete measures were then averaged for each participant. A Shaprio-Wilk's test was used to determine if the data was normally distributed. A one-way repeated measures analysis of variance (ANOVA) was used when data was normally distributed, whereas a Friedman's ANOVA was used when data was not normally distributed. Tukey's post hoc analysis was used when statically significant differences were found using a RM ANOVA, where a Dunn's multiple comparison post hoc was used when a Friedman's ANOVA was performed. Data was tested at $p<0.05$ for



all tests.

Figure 1. Instrumentation of the seat and the ergometer in the global coordinate system.

RESULTS: Footboards

A significant effect of SR was found on mean left anteroposterior footboard forces (F(3,27)=5.593, p=0.003, $\eta^2_{partial}$ =0.441), but not on the right footboard (F(3,27)=0.7112, 0.5538, $\eta^2_{partial}$=0.535). The 100 spm and max spm trials were found to be significantly greater than 60 spm. A significant effect of SR was found on mean lateral left (F(3,27)=2.966, p=0.0497, $\eta^2_{partial}$=0.494) and right footboard (F(3,27)=0.017, p=0.017, $\eta^2_{partial}$=0.489) force. The 60 spm trials were found to be significantly greater than max spm trials. SR had a significant effect on anteroposterior left (F(1.648,14.83)=7.119, p=0.0092, $\eta^2_{partial}$=0.441) and right (F(3, 27)=10.36, p<0.0001, $\eta^2_{partial}$=0.535) footboard impulses. In the left footboard, the 60 spm trials were found to be significantly greater than 80 spm and max spm trials. In the right footboard, the 60 spm trials were found to be significantly smaller than 100 spm and max spm trials. SR had a significant effect on anteroposterior left footboard impulse*SR (F(3, 27)=7.060, p=0.0012, $\eta^2_{partial}$ =0.0440). The 60 spm trials were found to be significantly greater than 100 spm and max spm trials, and the 80 spm trials were found to be significantly greater than max spm trials.

SR had a significant effect on lateral left (F(1.262, 11.36)=8.798, p=0.0093, $\eta^2_{partial}$ =0.494) and right (F(1.204,10.83)=8.603, p=0.0112, $\eta^2_{partial}$ =0.489) footboard impulses. In the left footboard, the 100 spm trials were found to be significantly smaller than 60 spm and 80 spm trials. In the right footboard, the 100 spm trials were found to be significantly smaller than 60spm and 80spm trials. SR had a significant effect on right footboard lateral impulse*SR (F(3, 27)=3.393, p=0.0322, $\eta^2_{partial}$ =0.273). The 60 spm trials were found to be significantly greater than 100 spm trials.

SR had a significant effect on vertical left footboard impulse (χ2(3)=9.0, p=0.0293, *W*=0.3), but not in the right footboard (χ2(3)=4.44, p=0.2177, *W*=0.148), found using Friedman's ANOVAs. In the left footboard, the 60 spm trials were significantly smaller than max spm trials.

Seat

A significant effect of SR was found on mean vertical seat force (χ2(3)=9.96, p=0.0189,

W=0.332), tested using a Friedman's ANOVA. The 60 spm trials were found to be significantly greater than max spm trials.
SR had a significant effect on seat lateral impulse (F(3, 27)=4.889, p=0.0077, $\eta^2_{partial}$=0.352). The 60 spm trials were found to have a significantly greater impulse when compared with 100 spm and max spm trials. SR had a significant effect on seat anteroposterior impulse (F(1.364, 12.27)=13.24, p=0.0012, $\eta^2_{partial}$=0.172). The 60 spm trials were found to have a significantly greater impulse when compared with 80 spm,100 spm and max spm trials, as well 80 spm trials were found to have greater impulse than max spm trials.
SR had a significant effect on vertical seat impulse (χ2(3)=30, p<0.0001, *W*=0.99), found using a Friedman's ANOVA. The 60 spm trials were significantly smaller than 100 spm and max spm trials, as well the 80 spm trials were significantly smaller than max spm trials.

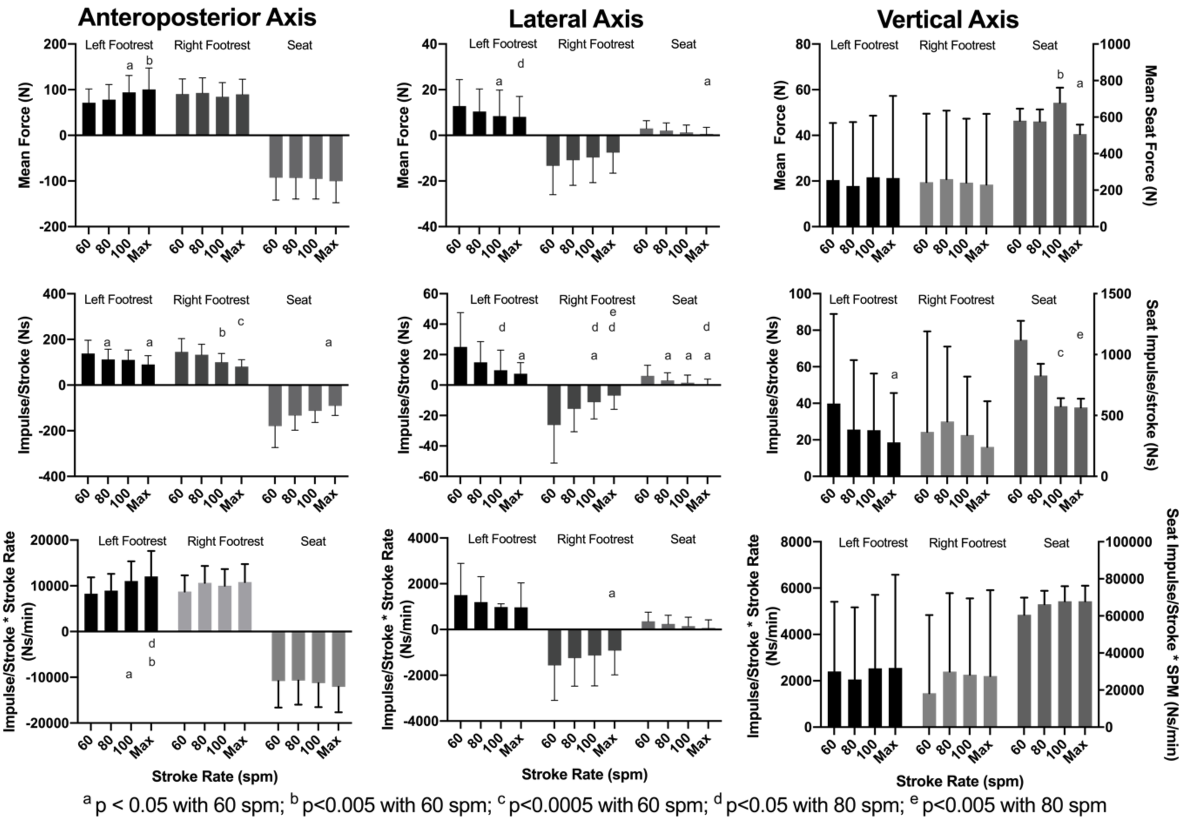


Figure 2. Mean, impulse, and impulse*stroke rate during four stroke rate conditions (mean ± standard deviation)

DISCUSSION: The aim of this study was to determine if SR had an effect on the kayak ergometer footboard and seat forces. It was determined that, with the exception of right footboard vertical forces, impulse significantly decreases as stroke rate increases. Impulse*SR was only observed to have significant changes in right lateral and left anteroposterior footboard forces. In addition, it was found that average lateral footboard forces significantly decrease, and left anteroposterior footboard and vertical seat force significantly increase with an increase in SR. These results suggest that adaptations to the increased SR are lateralised and dependent on the right paddle- left footboard kinetic link.
Higher stroke rates are known to be related to higher velocities (Gomes et al., 2020), where increases in propulsive force production can increase velocity through greater displacements during the water phase (McDonnell et al., 2013). It is important to understand the links between these two measures. Previous work has shown that net paddle impulse decreases as stroke rate increases (Gomes et al. 2015). The results of the present study are consistent with these findings in the footboards and seat impulses, apart from the lateral impulses measured in the

left anteroposterior footboard impulse and right lateral footboard impulse, where impulse per stroke cycle decreased as SR increased. At higher SRs, the smaller period of a stroke cycle likely impacts the impulses calculated. Impulse*SR was used as a proxy of the work completed at a given stroke rate. The results of the current study showed impulse*SR was not greatly affected by SR in the footboard and seat.

Although only significant in the left footboard, average lateral forces in the footboard and seat were observed to decrease as SR increased. This resulted in a non-significant decrease in lateral impulse*SR. This could possibly be a result of athletes having optimized their movements at higher stroke rates on-water and using these learned behaviours on an ergometer. In an on-water kayak shell, lateral forces should be minimized as they contribute to the rolling of the boat. Increased roll movements affect the drag experienced by the hull of the boat.

Impulse per stroke cycle was more affected by stroke rate than average force was. This presents an opportunity for improvement in athletes force production, further demonstrating that increasing force production at higher stroke rates can increase impulse and better contribute to the propulsive force production. This study presents an approach to analyse three-dimensional force data in the kayak seat and footboard on an ergometer. With some adaptions, including the waterproofing of equipment, the current methods of collection present a system to collect three-dimensional data on-water. This provides an exciting opportunity for biomechanists to better understand the implications of force production on forward propulsion and velocity in sprint kayakers.

CONCLUSION: Stroke rate affects seat and footboard impulse more than it affects mean force. Secondly, adaptation to SR is shown to be asymmetric. This reinforce the principle that athletes should strive to increase their impulse at higher stroke rates.

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