SPRINT KAYAKER'S KINETIC ASYMMETRIES AT INCREASING STROKE RATES

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Kinetic movement asymmetries are known to affect factors of performance, increase the likelihood of injury, and to decrease with increased cadences. The aim of this study was to determine if stroke rate affects asymmetry indexes (ASI) in the kayak ergometer footboards and seat. A significant main effect of stroke rate was found on footboard mediolateral total stroke cycle impulse (TSI) ASI ($p<0.005$) where asymmetry index increased with stroke rate, footboard anteroposterior TSI ASI ($p<0.005$) where an inverted U-shaped relationship was found with stroke rate, and footboard roll total stroke cycle angular impulse (TSAI) ASI ($p<0.001$) where an inverted U-shaped relationship was found with stroke rate, and seat mediolateral TSI ASI ($p<0.05$) where it decreased with stroke rate. The results of this study show that footboard and seat lateral forces counteract each other.

KEYWORDS: kayak, asymmetry, kinetics, cadence.

INTRODUCTION: In kayaking, ergometers are used for research, training, and performance testing. To date, the kayak paddle force profile has been studied, where the forces at the seat and footboard are not well understood. In sprint kayaking, the upper body is the main contributor to force production (Micheal et al., 2009; Shephard, 1987); however, mean kayak speed decreases by 16 % and mean paddle force decreases by 21 % when lower body movement is constrained (Nilsson and Rosdahl, 2016). Therefore, the lower body forces should also be considered when assessing measures of performance.

In a performance analysis context, it is important to understand an athlete's level of asymmetry to make corrections to their training program and reduce the likelihood of injury. Kayakers' lower body force and moment asymmetries have not yet been studied in any plane. Therefore, the purpose of this study is to determine if stroke rate influences the level of asymmetry on a kayak ergometer. It is hypothesized that as kayaking stroke rate increases on an ergometer, the asymmetry indexes (ASI) between left and right footboard, and seat forces will decrease.

METHODS: The instrumented ergometer has been presented previously (Miller et al., 2021) Briefly, 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 adjusted to participant's preferences. All data were collected at 1000 Hz. Ten participants (4 females/ 6 males, 20 ± 6 years, 72 ± 9 kg, 12 ± 5 years spent kayaking) of provincial to national team level were recruited. Participants were asked to perform a 10-minute warm-up prior to completing four randomized 30-second trials at 60 strokes per minute (spm), 80 spm, 100 spm, and maximum (max) spm with a three-minute rest between trials. Recorded forces were translated into a global coordinate system. Ten stroke cycles were analyzed for each individual trial. Mean force, and impulse discrete measures were identified for the individual components (anteroposterior, lateral, and vertical) of the resultant forces within each stroke cycle. Impulse*stroke rate were calculated to approximate impulse per minute. A Shapiro-Wilk's test was used to determine if the data were normally distributed. A one-way repeated measures analysis of variance (ANOVA) was used when data were normally distributed, whereas a Friedman's ANOVA was used when data were 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 were tested at $p<0.05$ for all tests.

An asymmetry index (ASI) was calculated for all discrete measures of force and moments.

$$ASI(\%) = \frac{\left|\left(|X_{left}|-|X_{right}|\right)\right|}{\left(|X_{left}|+|X_{right}|\right)*0.5} * 100$$

where Xleft is the measure of the left side, Xright is the measure of the right side, and ASI is the calculated ASI. An ASI equal to zero, corresponds to complete symmetry. The ASI was calculated to have no direction to the value.

RESULTS: The ASIs are presented in the ergometer global coordinate system, and are separated into the anteroposterior, lateral, and vertical axis. The longitudinal axis represents the anteroposterior axis, which characterizes the push and pull forces and the roll moment in the footboard and seat. The lateral axis presents the lateral force and pitch moments in the footboard and seat. The vertical axis presents the vertical forces and yaw moments in the footboard and seat. A summary of the calculated p-values is presented in Table 1. Stroke rate had a significant effect on ASIs on the mediolateral ($p < 0.005$, increases with stroke rate) and anteroposterior TSI in the footboard ($p < 0.01$, increases with stroke rate), roll TSAI in the footboard ($p < 0.0005$, inverted U-relationship with stroke rate), and mediolateral TSI in the footboard ($p < 0.05$, decreases with stroke rate; Figure 1), as well as on average lateral footboard force ASI ($p < 0.005$, increase with stroke rate).

DISCUSSION: The aim of this work was to establish if paddling at different rates changes the asymmetries of selected discrete kinetic variables acting on the paddle, footboard, and seat. It was hypothesized that kayaking ASIs would decrease as stroke rate increased since this has been found in other sports. This hypothesis was found to be too broad and should have focused on forces and moments that have a large impact on the performance of kayaking athletes (i.e., anteroposterior forces, roll moments, and yaw moments). For example, roll and yaw have a greater impact on the drag forces experienced while kayaking on the water (Gomes et al., 2017), and would be more important to focus on than the pitch moment. The findings of this work show that the average lateral TSI and average force in the footboard ASI increase as stroke rate increases (Figure 1), where the seat mediolateral TSI in the footboard ASI decreases as stroke rate increases (Figure 1). As well, the anteroposterior TSI in the footboard ASI increases as the stroke rate increases.

The mediolateral left and right footboard forces were measured to have lateral forces on both the left and right sides, suggesting that the lateral forces are used to counter the paddle forces. On the ergometer, the paddle is attached to the flywheel via a rope connection. At this connection point, there would be a singular force vector in the direction of the rope, where the pulley system attempts to maintain constant tension between the paddle and the flywheel, and the rope is angled towards the centre of the ergometer during the aerial phase. In addition, the ergometer is suggested to apply tension through all aerial phases of the stroke cycle (Fleming et al., 2012), which is not present in on-water kayaking (Gomes et al., 2020). As stroke rate increases, the rate at which the flywheel spins, increases. This causes an increased anterior-medial pulling force between the paddle and the ergometer via the rope. This force would need to be counteracted elsewhere in the boat athlete system.

The footboard is likely being used to compensate for asymmetrical forces in the paddle. It was found that stroke rate had a significant effect on the mediolateral footboard TSI ASI ($p < 0.005$), where the ASI increases as the stroke rate increases (Figure 1A). The stroke rate also had a significant effect on the ASIs of the average mediolateral seat forces, but in contrast, the ASI decreased with increases in stroke rate ($p < 0.0005$; Figure 1D). Larger footboard lateral forces (7.4 – 26.2 N) were observed when compared with the seat lateral forces (0.5 – 6.9 N). With small seat force asymmetries at high stroke rates, it is likely that the footboard is used to counteract the opposing paddle forces as no other propulsive or drag forces are present in the athlete-boat system.

On the water, the footboard force application is often used to keep the boat displacing linearly through the water (Begon et al., 2009). Athletes have a greater control over the linear and angular displacements of the boat through the footboard, when compared with the seat. On ergometers, the athletes' feet are directly connected to the footboard via thick cloth straps, while the athlete has no direct connection to the seat. As well, the individual foot locations on the footboard have a greater radius of gyration when compared with the seat, as they are located further from the centre of rotation in both the anteroposterior and lateral planes. Having a larger radius of gyration in the footboard allows the athlete to create a greater moment with the use of less force than would be needed to create the same moment about the seat. As a result, athletes will likely have consciously or subconsciously developed a pattern of controlling the boat's linear and angular movements through the footboard while on water. This learned pattern of movement and force application is likely transferred into ergometer kayaking and can be observed in the lateral forces and moments observed in this work and their ASIs at different stroke rates.

The average roll moment ASI was observed to have an inverted U-relationship with stroke rate ($p < 0.01$; Figure 1C), where the ASI was the smallest at maximum stroke rate ($p < 0.0005$). In kayaking, a sport in which athletes must keep their centre of gravity over a narrow boat shell, the roll and yaw moments have a greater effect on the hydrodynamic drag force than the pitch moment (Gomes et al., 2017). This is because roll and yaw moments greatly increase the amount of the boat's wetted surface area, which increases drag forces (Gomes et al., 2017). The finding that the average roll moment ASI reduced is at high stroke rates supports the idea that the athletes consciously or subconsciously decrease the roll moment to optimize their movements by decreasing the drag forces.

Large differences in pull forces were found both between individuals and within certain individuals' stroke rate conditions. This work has found that some individuals do not pull on the foot straps with one or both feet and some individuals pulled with one or both feet in some conditions and did not pull in other conditions. The differences in pushing and pulling forces between feet can be observed in the group left and right anteroposterior minimum footboard forces, where minimum anteroposterior forces would be considered the equivalent to peak pulling forces. The differences ranged from 3.7 N to 20.8 N.

The footboard pulling forces are in the direction of the paddle movement and possibly contribute to the propulsive forces in the athlete-boat system. It is known that the paddle forces translate through the body and into the boat to create forward propulsion, so it is not unreasonable to assume that forces exerted in the footboard can assist with the production of paddle forces. Therefore, it is surprising to see that not all athletes pull on the footboard straps. The lack of pull force by some athletes may be a result of a change in technique used when on the ergometer or that some athletes do not effectively use the footboard straps.

Table 1. The effect of stroke rate on the asymmetry index in the footboard and seat

Force Application Point	Axis	ASI Outcome Measures				
		Mean Force	COP	Mean Moment	TSI	TSAI
Footboard	Anteroposterior	0.788		0.271	0.0017*	0.0004*
	Lateral	0.0014*			0.0014*	
	Vertical	0.564		0.672	0.193	0.616
	x-axis		0.735			
Seat	Anteroposterior			0.840		0.724
	Lateral	0.197			0.0136*	
	Vertical			0.472		0.124
	x-axis		0.291			

Note. *, significant result; asymmetry index, ASI; center of pressure, COP; total stroke cycle impulse, TSI; total stroke cycle angular impulse, TSAI. If a RM ANOVA and Friedman's ANOVA were calculated then only the RM ANOVA p-value was presented, where if only a Friedman's ANOVA was calculated, then the p-value in this table was representative of the Friedman's ANOVA p-value.

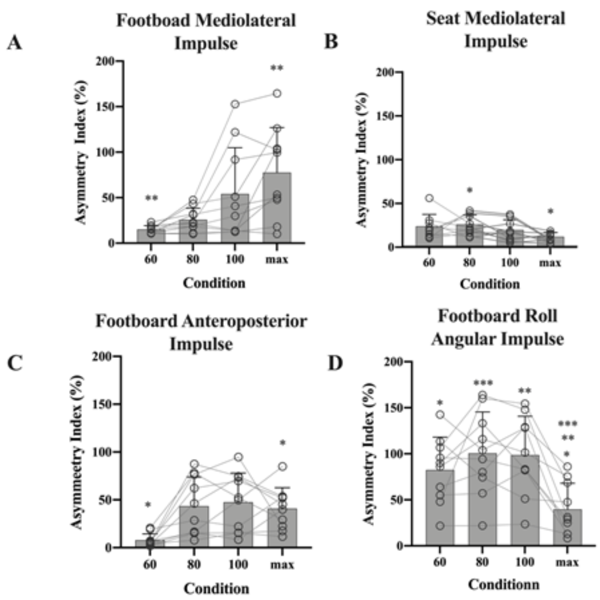

Figure 1: Stroke cycle had a significant effect on total stroke cycle impulse (TSI) and total stroke cycle angular impulse (TSAI). This graph represents individual participant TSI and TSAI asymmetry indexes (ASI) (circles) compared to the group means and standard deviations (bars). (A) Stroke rate had a significant effect on mediolateral TSI ASI in the footboard, where ASI increased with stroke rate, (B) stroke rate had a significant effect on mediolateral TSI ASI in the seat, where 80 spm demonstrated the highest ASI of the four conditions, and the ASI decreased from 80 – maximum spm, (C) stroke rate had a significant effect on anteroposterior TSI ASI in the footboard, where ASI increased until 100 strokes per minute (spm) and then slightly decreased at maximum spm, (D) stroke rate had a significant effect on roll TSAI ASI in the footboard, where ASI was lowest at max spm. * $p < 0.05$, ** $p < 0.005$, *** $p < 0.0005$

CONCLUSION: It can be concluded that the mediolateral and anteroposterior footboard total stroke cycle impulse asymmetry indices increase as stroke rate increases, the roll angular impulse ASI has an inverted U-relationship with stroke rate, and that mediolateral seat impulse ASI decreases with increased stroke rate. These results can be interpreted to show that forces and moments acting at the footboard and seat counteract each other to maintain the athletes on their seat while on the ergometer and effectively reduce the lateral deviations of the boat.

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