THE ANALYSIS OF FORWARD ACCELERATION ASYMMETRIES DURING ON-WATER SPRINT KAYAKING

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The study's aims were to (1) determine normative values of the critical features of forward acceleration asymmetries in sprint kayaking, and (2) to investigate the effect of stroke rate (SR) on these asymmetries. Fifteen national-to-world class level sprint kayak athletes completed four, 30-second on-water trials at four different SR's (60, 80, 100, and maximum strokes per minute). Critical features (i.e., maximum, minimum and range) from forward acceleration waveforms were extracted from ten single stroke cycles (i.e., five left and five right) for each trial. An asymmetry index (ASI) was used to determine the amount of asymmetry between left and right strokes for each critical feature. ASI's of at least 8.0±11.7% up to 19.3±12.4% existed for all critical features combined. A one-way repeated measures ANOVA with linear trend analyses showed all critical feature ASI's increased with SR. These results provide appropriate asymmetry benchmarks for coaches to assess technical efficiency during on-water sprint kayaking and exude the importance of analyzing left and right single strokes separately.

KEYWORDS: kayak, asymmetry, elite, acceleration, cyclical, technique

INTRODUCTION: The goal of sprint kayaking is to reach a finish line faster than your opponent(s), thus athletes strive to obtain the greatest average kayak velocity. To increase velocity, athletes must propel themselves forward by applying large amounts of force to the water via a double-bladed paddle. As the energy exerted transfers from the water, through the athlete and to the boat, it causes the boat to increase its acceleration in the forward direction (i.e., towards the finish line). Throughout the stroke the forward acceleration fluctuates from positive (i.e., entry and pull phases of the stroke) to negative (i.e., exit and aerial phases of the stroke) (Gomes et al., 2020). Information regarding how the kayak accelerates in the water may uncover technical inefficiencies that could be hindering performance. Prior to investigating the kayak's intra-stroke cycle acceleration (i.e., the double stroke), it is important to determine if left and right strokes within the stroke cycle are symmetrical. This information is also important for identifying other inefficiencies in the stroke, as unnecessary movements not in the intended direction of travel may be affecting performance (Gomes et al., 2018; Michael et al., 2009). Furthermore, little information is available relating stroke asymmetries to the risk of injury (Bjerkefors et al., 2017). Although relating stroke asymmetries to injury incidence is not an aim of this paper, we do believe it is important to identify if on-water asymmetries are common in sprint kayaking.

Researchers have investigated the symmetry of sprint kayaking kinematics and kinetics in the past. However, these studies have primarily been collected on ergometers and have not related their findings to on-water performance parameters, like kayak velocity (Bjerkefors et al., 2017; Limonta et al., 2010). Despite limitations in ecological validity, elite and intermediate-level sprint kayakers had asymmetries of 12-28.6% in maximum elbow flexion and 2.3-5.9% in knee range of motion while paddling on a kayak ergometer (Limonta et al., 2010). Research has also shown the right stroke to have greater propulsive power output than the left stroke in elite sprint kayakers (Bjerkefors et al., 2017). Finally, another study used a computational fluid dynamics simulation to model the effect of stroke-depth asymmetries on kayak velocity (Harrison et al., 2019). They suggested asymmetries reduce velocity by 0.7-0.9% per stroke, and since kayak races can be won by milliseconds, the potential detrimental effects of asymmetries seem to be significant.

The study's aims were to (1) determine normative values of the critical features of forward acceleration asymmetries (i.e., range, maximum, and minimum) in sprint kayaking, and (2) to investigate the effect of stroke rate (SR) on these asymmetries. As SR (and velocity) increases, we would expect power output to increase as well. Previous research showed that power asymmetries in ergometer kayaking was not modulated by SR (Bjerkefors et al., 2017). Our hypothesis is that on-water forward acceleration asymmetries will not change as SR increases.

METHODS: Fifteen national-to-world class level sprint kayakers (8 females, 21.9±5.4 years old, 1.75±0.07 m, 73.0±9.4 kg, 12.7±5.0 years of kayaking experience) paddled on a marked 1000 m sprint kayak racecourse with participants using their own personal kayaks. The study was approved by Dalhousie University's Research Ethics Board. The experimental protocol consisted of an individual-led warm-up (ten minutes followed by a five-minute rest period) and then four paddling trials (30-seconds, SRs in random order: 60 strokes per minute (spm), 80 spm, 100 spm, and maximum spm). Three-minute-long rest periods were interspersed between trials. Participants started the trial from a static position and were instructed to increase their SR slowly until they reached the intended trial SR within ~10 seconds. The average SR for the final 20 seconds of the trial was required to be within ±5 spm of the intended SR for that trial to be analyzed. All data were collected in calm environmental conditions (15.8±3.5˚C air temperature, 14.3±2.1˚C water temperature, 0.73±0.51 $m\cdot s^{-1}$ tail wind). Kayak velocity and forward acceleration data were collected for each trial using a 50 Hz tri-axial inertial measurement unit (±2 *g*, IMU: LMS330DL, STMicroelectronics©, Indiana, USA) with a 5 Hz GPS/GNSS module. The IMU was attached to the kayak on the midline of the longitudinal axis of the boat, 0.15 m posterior to the kayak's cockpit.

The kayak's forward acceleration was analyzed by extracting ten single stroke waveforms (5 per side) from each SR trial when athletes were paddling at a constant velocity (i.e., <5% velocity change during analysis period). Data were filtered using a low-pass, 4^{th} order Butterworth filter with a cut-off frequency of 6 Hz and separated into left and right strokes. Discrete point analysis was used to extract pre-determined critical features (i.e., minimum, maximum, and range (i.e., maximum minus minimum)) from each of the ten forward acceleration waveforms. Each critical feature variable from the left and right strokes were then averaged for each SR trial. Asymmetries between the left and right strokes were calculated using an asymmetry index (ASI), where an ASI of 0% indicated the left stroke was equal to the right stroke (i.e., the left and right strokes were symmetric) (Robinson et al., 1987).

$$ASI(\%) = \frac{\left|(Acceleration_{left} - Acceleration_{right})\right|}{½\left|(Acceleration_{left} + Acceleration_{right})\right|} \bullet 100\%$$

A one-way, repeated measures ANOVA with a Tukey's post-hoc test was used to determine if SR was associated with different ASI distributions. Effect sizes are presented using partial eta squared (η^2). A linear trend test was used to determine if ASI means increased (or decreased) systematically as SR increased. Data were analyzed using GraphPad Prism (v.9.3.1, San Diego, CA, USA). The alpha value for statistical significance was set at α = 0.05.

RESULTS: Average kayak velocities increased as SR conditions increased (Table 1). There was a significant effect of the SR condition on the maximum forward acceleration ASI ($F(2.6, 36.7)=4.1$, $P=0.016$, $\eta^2=0.23$). There was no significant effect of the SR condition on the minimum ($F(2.2, 30.6)=1.9$, $P=0.163$, $\eta^2=0.12$) or range of forward acceleration ASI's ($F(2.0, 28.7)=2.8$, $P=0.075$, $\eta^2=0.17$). Linear trend analyses were statistically significant for all three critical features (Table 1). Group average and individual range, maximum and minimum forward acceleration ASI's for each SR condition are shown in Table 1 and Figure 1, respectively.

Table 1: Average ASI and velocity for each SR condition, as well as linear trend results.

	60 spm	80 spm	100 spm	Maximum spm	Linear Trend?
Stroke Rate (spm)	61.0±2.4	80.4±2.2	99.8±2.6	129.1±13.9	-
Velocity (m•s^{-1})	3.53±0.24	4.01±0.18	4.51±0.28	4.99±0.53	-
ASI Range (%)	8.0±11.7	10.1±14.1	10.7±13.2	13.6±10.8	P=0.007, b=1.71
ASI Maximum (%)	10.3±13.6	10.7±16.3	15.3±19.4	16.4±16.0	P=0.002, b=2.28
ASI Minimum (%)	9.6±10.1	13.4±17.0	16.0±13.9	19.3±12.4	P=0.022, b=3.17

Data presented as mean ± standard deviation. *P, p*-value; *b*, slope.

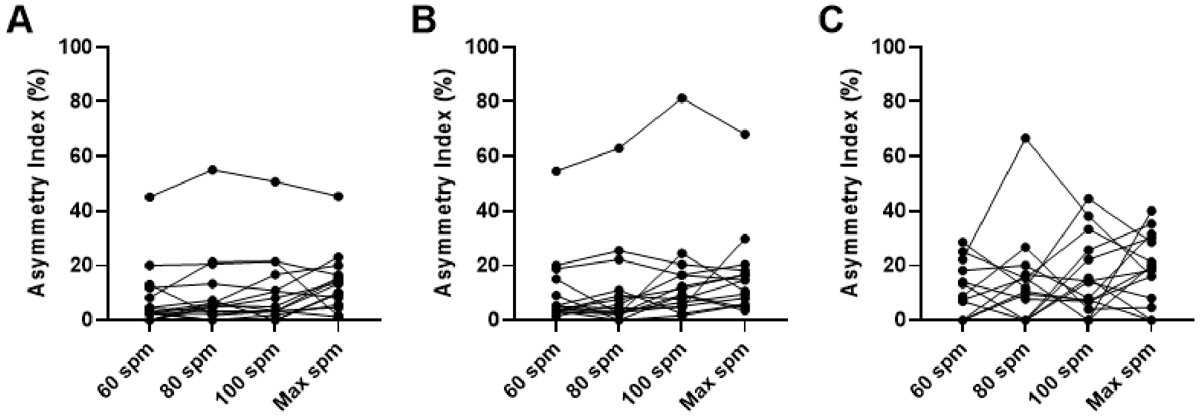

Figure 1. Individual asymmetry indexes (ASI) for each SR condition for (A) range, (B) maximum, and (C) minimum forward acceleration values. Max, maximum SR condition.

DISCUSSION: The primary findings from this research are (1) critical feature asymmetries from forward acceleration waveforms exist, even in world class level athletes, and (2) there was a positive linear trend between asymmetries and SR. This is the first study to investigate forward acceleration asymmetries during on-water sprint kayaking. The results from this study are important because they inform the sport biomechanist and coach to analyze the left and right strokes independently. These data provide normative asymmetry values from national-to-world class level sprint kayakers, which could provide appropriate benchmarks when assessing technical efficiency. For example, on average the lowest amount of asymmetry was approximately 8%, which was found in the range of forward acceleration ASI during paddling at 60 spm. Therefore, it may be worth the coach's time to attempt to alter the athlete's technique if they are found to have much greater asymmetry than this normative value. This can be seen in Panels A and B of Figure 1, where one athlete produced range and maximum ASI values varying between 45-55% and 54-81%, respectively.

Our results cause us to reject the null hypothesis for this study, as the data showed asymmetries of forward acceleration critical features increased as SR increased. Therefore, if athletes are shown to have a large forward acceleration asymmetry between sides of the stroke cycle, it can be expected to increase as their SR increases. Although a small asymmetry may not affect technical efficiency at lower SR's (i.e., during training), it can be expected that inefficiencies will increase as the athlete reaches higher SR's (i.e., during racing). Our hypothesis was based on previous research that showed power asymmetries in ergometer kayaking were not modulated due to SR. This is interesting as it would be expected that forward acceleration of the kayak caused by one stroke would be dependent on the power output from that stroke. Due to the potential effect on boat steering, and previous research citing the detrimental effect of unnecessary or erratic boat movements on performance (Gomes et al., 2018; Mann & Kearney, 1980; Michael et al., 2009), future research should investigate how asymmetries affect other planes of boat movement as well (i.e., vertical and lateral accelerations, and pitch, yaw, and roll angular velocities).

From a practical application point of view, this research shows the importance of using inertial measurement units as a method to detect asymmetries in sprint kayak technique. As these sensors continue to develop and be used in sport biomechanics, it is expected that more information about sprint kayak technique will be visible. For example, many coaches still rely on video to dissect their athlete's technique. Despite common limitations, this seems to be a good method of analyzing technical flaws. However, with high-resolution information coming directly from the boat via an IMU, even more ways to detect inefficiencies will continue to increase performance.

Although we believe the results from this study will inform coaches and athletes of how asymmetries are modulated at different intensities (i.e., stroke rates), there are some limitations. One limitation is that we only investigated asymmetries in one plane. As other researchers have pointed out in the past, a large portion of sprint kayaking inefficiencies are due to boat movements in planes not in the direction of travel (Brown et al., 2011; Gomes et al., 2018; Michael et al., 2009). For example, Brown et al., (2011) found that higher-level sprint kayakers had less boat motion (i.e., pitch and roll) while racing than their more novice counterparts. Although the mechanism for why more boat movement is detrimental to kayak performance has not been measured directly, it is likely due to the increase amount of friction drag on the kayak (Gomes et al., 2018).

CONCLUSION: This study provided normative asymmetry values of critical features from forward acceleration waveforms in sprint kayaking. These results can be used to identify an athlete's level of asymmetry, which may aid in developing better technique. Another important result from this research was the identification of a positive linear trend between asymmetry magnitude and SR. Sport biomechanists and coaches will now understand the importance of analyzing the left and right kayak strokes independently of one another.

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