RELIABILITY OF DIFFERENT METHODS OF DETERMINING INDIVIDUAL INTER-STROKE INTERVALS IN SPRINT KAYAKING

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The purpose of this study was to explore the reliability of methods for rapidly determining inter-stroke intervals (ISI) of individual kayakers. One participant performed two 150 m trials at a rate of 80 single-strokes/min. ISI were calculated using two criterion measures, visual identification of blade immersion from video record (VID) and peaks in longitudinal acceleration of the kayak hull derrived from a kayak mounted accelerometer (ACC). These measures were compared to ISI from peak footrest force (FRP), initiation of footrest force from a fixed load cell (FRT), paddle Y axis rotational velocity (PAP) and paddle X axis acceleration via an IMU (PAA). Least products regression analysis (LPR) revealed that FRP showed the highest reliability, with no fixed or proportional bias compared to VID or ACC. High ISI during the initial strokes influenced the results of the LPR. A framework for investigating the reliability of ISI using LPR is suggested where the initial strokes are removed prior to analysis.

KEYWORDS: coordination, kayak, reliability, timing

INTRODUCTION: The derivation of inter-stroke intervals (ISI) allows for the analysis of pacing strategies, stroke efficiency, performance consistency and interpersonal coordination (McDonnell, 2013; Tay & Kong, 2017; Vadai, Gingl, Mingesz, & Makan, 2013). ISI are most commonly derived from longitudinal acceleration of the kayak hull (ACC) or visual assessment of key stroke events, often blade insertion into the water (VID) (Tay & Kong, 2017). ACC has been demonstrated to be related to performance, however ACC does not allow for assessment individual athletes' ISI in crew-boat events (Vadai et al., 2013). VID does allow for the assessment of individual athletes' ISI, however its relationship to performance has not been demonstrated.

Determining ISI for each individual is required to study coordination between kayakers within crew-boats, which is hypothesised to be a key performance factor, though the optimal coordination strategies and rationale for performance gain are unclear (Shin, 2016; Tay & Kong, 2017). To investigate crew coordination, a rapid method of assessing individual ISI is required. VID is not a rapid analysis method, with feedback often delayed significantly after task performance and analysis of large data-sets is time consuming. The purpose of this study was to explore the reliability of potential methods for rapidly determining ISI of individual kayakers and to compare them to two criterion methods: VID, which is currently the preferred option of coaches and sports scientists; and ACC, which although it cannot asses individual ISI during crew-boat performance, has an established relationship with performance.

METHODS: A single male participant (age, 32 years; 1.8 m; 88 kg) with Olympic level kayak experience performed two 150 m self paced trials from a standing start at a cadence of 80 single-strokes/min. The criterion measures were compared to measures derived from footrest force (FRF) and paddle movement (PA).

VID. The trials were filmed perpendicular to the sagittal plane using a high speed camera (Iphone 6S, Apple, Cupertino, CA) operating at 240 Hz. ISI was calculated as the time between same-side paddle blade immersion into the water (each double-stroke), using techniques described by Tay and Kong (2016). All following methods also calculate ISI as double-strokes.

ACC. Forward acceleration of the kayak was measured using an analogue 3-DOF accelerometer (ADXL335, Analog Devices, Norwood, Massachusetts) bolted to the kayak and recorded using a custom built data-logger at 100 Hz. A MATLAB (2017b, MathWorks, Natick, MA) script was used to smooth the data using a 6Hz fourth-order Butterworth low-pass filter and determine ISI between peak stroke accelerations.

FRF. Footrest force was collected using a compression load cell (TE Connectivity, FC2231-0000-0050-L) mounted to the kayak footrest and sampled at 100 Hz using a custom built data-logger. A MATLAB script was used to smooth the data using a 6Hz fourth-order Butterworth low-pass filter and determine ISI between peaks (FRP) and troughs (FRT) of the footrest force of each stroke (Figure 1). For FRT ISI 1, the initial point was was visually identified as the first rise in FRF.

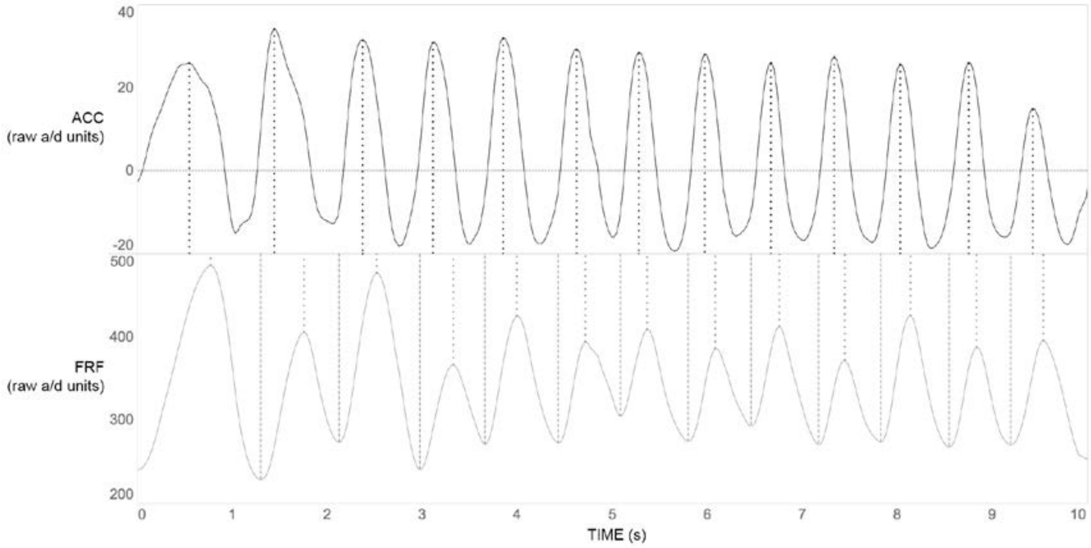

Figure 1. ACC and FRF from a section of trial 1 beginning at the visually identified initial data point of FRT. Vertical reference lines show peaks identified for ISI calculation. Black dotted = ACC, grey dotted = FRP, grey dashed = FRT

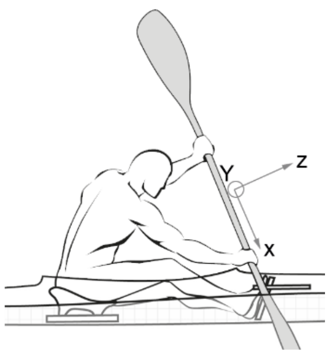

Figure 1. Orientation of paddle mounted IMU

PA. Paddle motion was captured using a 9 DOF IMU mounted to the centre of the paddle shaft using dual-lock adhesive reclosable fastener (Dual-Lock™, 3M, Maplewood, MN) sampling at 100 Hz (minimax b5, Catapult, Melbourne, Australia) (Figure 2). Acceleration and angular velocity were logged in each axis and a spectral power analysis was performed to select the most appopriate channel for ISI determination. From this analysis, paddle angular velocity about the Y axis (PAP) and X axis acceleration (PAA) were selected for ISI analysis as they showed the highest proportion of power around the guide rate of 0.7 Hz and least power around harmonic frequencies. Raw data were smoothed using a 6Hz fourth-order Butterworth low-pass filter and ISI were calculated using a MATLAB script identifying stroke peaks and and troughs in each signal.

DATA ANALYSIS. ISI data were analysed in Microsoft Excel (2013, Redmond, WA). Systematic differences were investigated using a least products regression analysis (LPR). The data were inspected visually and analysed using 95% confidence intervals (95%CI) of the values of a and b given the equation of the LPR regression line as y = a + b x where a represents the y intercept and b represents the slope (Ludbrook, 1997; Jolicouer & Mosimann, 1968). The parameters a and b are taken to represent proportional and fixed bias respectively, ideally measured as a=0 and b=1. If the 95%CI of a and b did not cross 0 and 1 respectively then this indicates either a fixed or a proportional bias. Initial analysis of the LPR illustrated the influence of outliers, which were derived from the initial strokes where ISI were larger. To assess the influence of these outliers, the data was derived into two subsets, FULL and SHORT. FULL included all strokes, SHORT excluded the first 4 strokes from the analysis.

RESULTS: 22 ISI were analysed in trial 1, 20 in trial 2. Mean ISI for the different methods in the FULL set were VID, 1.46 ± 0.11 s; ACC, 1.45 ± 0.07 s; FRP, 1.44 ± 0.07 s; FRT, 1.47 ± 0.13 s; PAP, 1.43 ± 0.11 s; PAA, 1.46 ±0.12 s. In the SHORT subset they were VID, 1.45 ± 0.03 s; ACC, 1.45 ± 0.05 s; FRP, 1.45 ± 0.05 s; FRT, 1.45 ± 0.07 s; PAP, 1.45 ± 0.04 s; PAA, 1.45 ±0.04 s. The output of the LPR analysis is shown in Figure 3 and the associated regression coefficients in Table 1. The methods which showed adequate reliability, as assesed by a lack of fixed or proportional bias in relation to VID were PAP in the FULL subset; FRP and PAA in the SHORT subset. In relation to ACC they were FRP in the FULL subset; FRP and PAA in the SHORT subset. Only the comparison of FRP to ACC showed a lack of bias in both the SHORT and FULL subsets. All other comparisons indicated a lack of reliability, exhibiting both fixed and proportional bias.

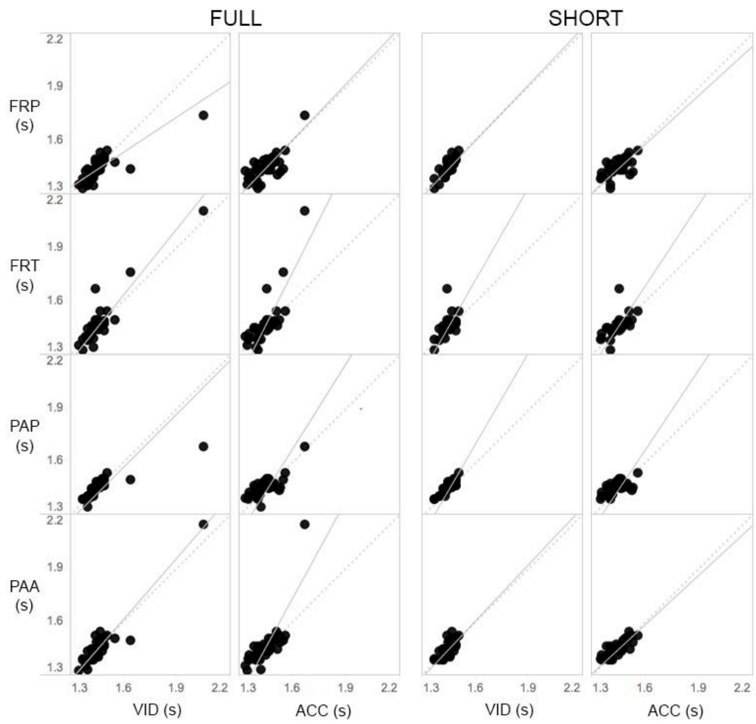

Figure 2. LPR analysis of methods for calculating ISI. Grey reference line indicates LPR fit, dotted reference line indicates line of identity

Table 1: LPR regression coefficients and the upper (UL) and lower (LL) limits of their 95% Confidence Intervals. Measures shown in bold indicate a lack of proportional of fixed bias

		VID											
		FRP			FRT			PAP			PAA		
			LL	UL		LL	UL		LL	UL		LL	UL
FULL	b	0.66	0.54	0.79	1.24	1.07	1.43	**1.00**	**0.75**	**1.33**	1.14	1.02	1.28
	a	0.48	0.29	0.65	-0.34	-0.63	-0.10	**-0.03**	**-0.51**	**0.33**	-0.22	-0.42	-0.04
SHORT	b	**1.05**	**0.81**	**1.36**	1.74	1.38	2.21	1.73	1.33	2.25	**1.06**	**0.83**	**1.36**
	a	**-0.08**	**-0.53**	**0.27**	-1.07	-1.75	-0.54	-1.07	-1.82	-0.49	**-0.09**	**-0.53**	**0.25**
		ACC											
		FRP			FRT			PAP			PAA		
			LL	UL		LL	UL		LL	UL		LL	UL
FULL	b	**1.05**	**0.84**	**1.31**	1.98	1.57	2.51	1.60	1.22	2.11	1.83	1.49	2.25
	a	**-0.08**	**-0.46**	**0.23**	-1.41	-2.17	-0.81	-0.90	-1.64	-0.34	-1.20	-1.81	-0.71
SHORT	b	**0.92**	**0.70**	**1.21**	1.53	1.14	2.05	1.51	1.13	2.02	**0.93**	**0.75**	**1.15**
	a	**0.11**	**-0.31**	**0.43**	-0.76	-1.52	-0.19	-0.76	-1.49	-0.21	**0.10**	**-0.23**	**0.36**

DISCUSSION: These results indicate that FRP, PAA and PAP show adequate reliability compared to either VID or ACC. The presence of outliers in the full data set has a significant effect on the reliability as assessed by LPR, likely due to the heteroscedastic nature of the error in the FULL subset. When distribution of data points around the LPR line are not evenly spread along the full measurement range then data points at one end of the distribution (typically when values are larger) have a strong influence on LPR. Mullineaux, Barnes and Batterham (1999) comment on the observation that heteroscedastic errors are common in sports medicine and science, as biological responses become more varied and measurement error increases with larger values. Smaller values tend towards zero assuming negative values are not possible, therefore the error around smaller values is often less. These factors are likely to be true in this case, and their influence on the outcome of the reliability analysis was that only two comparisons indicated reliability in the FULL subset, whereas four comparisons were reliable in the SHORT subset. Furthermore, in the FULL subset, different comparisons showed reliability compared to ACC and VID, whereas in the SHORT subset, the same two comparisons, FRP and PAA were reliable compared to ACC and VID. This indicates the proposed methods may only be suitable when assessing individual ISI across a limited range of values. Strokes taken at the start of trials may not be suitable for inclusion in comparative analysis of ISI using the proposed methods or should be analysed separately.

In the SHORT data-set both FRP and PAA showed reliability when compared to both ACC and VID. It can tentatively be suggested that these may be the most appropriate measures for assessing individual ISI. FRP was the only measure that was reliable across all comparisons, which suggests the importance of FRF during sprint kayaking, in agreement with Nilsson & Rosdahl (2016) who demonstrated that restricting leg movement during kayaking reduced mean kayak speed during a maximal effort trial by 16%. Analysis of ISI using both FRP and PAA could potentially provide further information on the nature of upper and lower body contributions to kayak velocity. Future studies should investigate using a larger sample size to asses whether these results can be generalised beyond the athlete used in this study.

CONCLUSION: Care must be taken in the choice of method for investigating ISI. Though these results suggest support for FRP being the most appropriate measure to assess individual ISI, further research is recommended using a larger sample size with a range of participant abilities. Future analysis of data sets should exclude the initial strokes or analyse them separately, with a focus on the error during large ISI. LPR was an appropriate method for analysing the reliability of different methods of ISI detection for the athlete analysed.

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