STROKE CHARACTERISTICS IN SPRINT KAYAKING – HOW DOES SEAT ORDER INFLUENCE SYNCHRONIZATION IN A K2 CREW BOAT?

CHERYL SIHUI TAY
Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616.
Email: cheryltsh@gmail.com

PUI WAH KONG
(Corresponding author)
Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616.
Email: puiwah.kong@nie.edu.sg

The purpose of this study was to investigate the how seat order in a K2 crew boat could influence the performance time and stroke synchronization during high intensity sprint kayaking. Sixteen national team sprint kayakers formed eight K2 crews based on preference. Each crew performed two 200-m segments at high intensity in their preferred order (e.g. Paddler A in front, Paddler B behind), and then the reversed order (i.e. Paddler B in front, Paddler A behind). Video analysis identified stroke synchronization based on a four-position model. Magnitude-based inferences were used for statistical analysis. The preferred seat order was 0.5 ± 1.8 s faster than the reversed seat order but the effect was *possibly trivial*. As four crews were faster in the reversed seat order, data were also rearranged to compare between the slower and faster trials. The faster trials were 1.5 ± 0.5 s quicker than the slower trials, which was a *very likely* effect. There was no clear effect of seat order on stroke synchronization between the two paddlers. Since faster timing does not always correspond with the preferred sear order, sprint kayak athletes are recommended to try both possible seat orders in a K2 crew boat rather than relying on preference alone.

Keywords: Team boat; paddling; preference; high intensity

1. Introduction

In sport, crew boat racing involves more than one person propelling a boat on water together using oars or paddles. Examples of crew boat racing include canoeing, kayaking, rowing, and dragon boat racing. To propel the boat forward on water, all crew members must paddle together to generate mechanical energy to overcome the drag force. A two-seater (K2) is the smallest unit of a crew boat in the Olympic sport of sprint kayaking. In a K2 crew boat, two athletes are seated in tandem and perform cyclical repetitions of a forward stroke using double-bladed paddles. For athletes trying out as a new crew in the K2, the first decision they have to make is on the seat order, i.e. who would sit in front and who would sit behind. While theoretically there should be a correct seat order that leads to the fastest performance time for a crew, the basis for how seat order in a K2 crew boat is determined is currently unclear.

The common practice used by many coaches and athletes in K2 crew boat kayaking is for the stronger paddler to sit at the back (stern) of the boat and the weaker paddler to sit in the front. There are anecdotal evidence advocating this practice, for example, an observational study of 42 sprint kayakers at the 2000 Sydney Olympics found that the taller and heavier athletes sat at the back seats in the crew boats.[1] The reason suggested was that the taller athletes were better able to paddle beyond the wider beam (width) of the sprint kayak at the back, whereas the front of the kayak has a more tapered and narrow shape. It was also noted that the front paddler in a K2 crew boat may opt to use the same or shorter paddle length compared to his/her usual length in a single boat (K1), while the back paddler may use a longer length to compensate for the wider beam at the back of the boat.[2] These observations, however, were made before the minimum boat width regulation was abolished around 2000. Anecdotal evidence of photographic analysis at international level sprint kayaking show a convention where the smaller stature athletes are seated in front, and the taller and presumably stronger athletes behind.[3] In a similar crew boat racing sport of rowing, the stronger rower is usually placed in the stroke seat of a rowing pair, which is the seat further from the direction of travel of the boat (backwards). Within ten experienced rowing pairs, the stroke seat rowers had higher peak forces than the boat seat rowers[4], although the difference was not statistically significant. Overall, despite commonly practised by coaches and athletes, there are insufficient scientific data to support that stronger paddler should sit at the back of the boat.

In contrast, other indirect evidence suggest that the opposite approach of having the stronger athlete sitting in front of the boat may be more beneficial. Computational fluid dynamics modelling of paddle blade designs in dragon boat racing suggest that the load experienced by an athlete seated at the front of the boat is greater than that at the back.[5] The model showed a stagnation on the power face of the paddle blade, and a wake created behind it, suggesting that the water at the back of the boat is faster flowing. As drag force is approximately proportional to the square of relative velocity, the force experienced by the athlete in front would be larger and hence the stronger athlete would be more suited to overcome the heavier load at the front seat position. This idea is also supported by an injury survey of elite dragon boat athletes which found that athletes seated in the front rows of a 22-crew standard boat were more predisposed to upper body musculoskeletal injuries as compared to athletes who sat at the back.[6] Nonetheless, these investigations were not specific to sprint kayaking where the size of the crew boats are comprises only two or four athletes, and the paddle blades have a winged design that affects the propulsion hydrodynamics.

Further investigation is needed to clarify the mismatch between the current coaching practice of having the stronger athlete seated at the back, versus the theory that the stronger athlete is more suited for the higher loads experienced in the front seat. Well-synchronized stroke patterns within a crew were suggested to be important for superior crew boat performance in sprint kayaking.[3] An observational study on sub-elite K2 crews reported that the stroke synchronization patterns varied greatly and there was no universal synchronization profile among well-trained sprint kayakers.[7] One study has compared the effects of three different K4 crew combinations from five female sprint kayakers on 500-m time trial performance.[8] Crew 3 was the best performing crew with higher 5-stroke segment peak acceleration, and was overall 2.0% faster than Crews 1 and 2. One reason for the better performance of Crew 3 was that the crew members were more synchronized in their strokes but there was insufficient information on the crew composition. Furthermore, out of the 120 permutations of a K4 crew from five athletes, only three configurations were tested in their study. To the authors' best knowledge, there has not yet been a study that systematically evaluates the effects of seat order on crew boat performance and stroke synchronization in sprint kayaking. To address this research gap, the present study will apply biomechanical engineering technique to solve a biological problem in the context of sport.

The purpose of the present study was to investigate how seat order of a K2 crew boat could influence performance time and stroke synchronization during high intensity sprint kayaking. It was hypothesized that 1) the performance time would be faster in a crew's preferred seat order than a reversed seat order, and 2) stroke synchronization would be more precise in the preferred seat order than the reversed seat order.

2. Methods

2.1. Participants

This study received ethical approval from the Nanyang Technological University Institutional Review Board (IRB-2014-12-022). Sixteen (8 males, 8 females) sub-elite sprint kayakers from a national team gave their informed written consent to participate in the present study (Table 1). The participants had about 10 years of competitive paddling experience and were highly motivated to perform well to be selected into the final competition team. Participants were healthy and free of injuries at the time of the study.

Table 1. Participant characteristics and personal K1 200-m performance of 16 athletes in the Singapore national team

Crew Members	Height (m)	Mass (kg)	Age (years)	Competitive Experience (years)	Personal K1 200-m time (s)
Men (n = 8)	1.74 (0.05)	73.8 (3.3)	23.9 (2.9)	10.4 (1.8)	38.2 (2.0)
Women (n = 8)	1.62 (0.05)	56.8 (6.8)	25.6 (3.7)	9.4 (3.3)	44.5 (2.0)

2.2. Study Design

This was an on-water investigation which involved eight pairs of K2 sprint kayaking crews performing high intensity trials. There were two experimental conditions: preferred seat order and reverse seat order. Within-crew comparison (preferred vs reverse orders) in performance time and stroke synchronization were made via video analysis. Magnitude-based inference was used in statistical analysis.

2.3. Procedures

This study took place when all sprint kayakers were trying out in single-sex K2 crew boats during their first crew boat training session of the competitive season. The pairings were assigned by their coach, but each pair of participants discussed and agreed on their own preferred seat order in the K2. The study was conducted at a reservoir training base with a 1000-m race course designated for sprint kayaking competition. Each crew was assigned a similar model of a K2 sprint kayak, and weighed to ensure it met the minimum competition weight of 18.00 kg. Where necessary, additional weights were secured to meet the minimum weight requirement. The seat and footrest fittings were customized by each participant to their preference. Participants used their personal paddles and wore their regular training attire. Before the experimental trials, each participant performed a self-selected warm-up on land.

The experiment protocol mimicked a typical crew boat try-out session for sprint kayakers in a new competitive season. For each seat order in the K2, participants performed 20 mins of light paddling followed by a high intensity 300-m trial. All participants sat in their preferred order first (e.g. Participant A in front, Participant B behind), followed by the reversed seat order (e.g. Participant B in front, Participant A behind). This protocol was chosen to replicate the actual process that the crews would perform when they are trying out in crew boats for the first time. When seat order was reversed, participants were given 10 mins to adjust their seat and footrest fittings if needed. Participants were instructed to paddle at a rating between 15 to 16 on the Borg 6–20 scale, which represents a hard effort.[9] They were familiar with the Borg 6–20 scale as this scale is used in their regular training sessions. After each trial, participants were asked to verify if they had indeed performed at the instructed rating of perceived exertion. Using self-perceived rating of exertion to moderate paddling intensity has also been used previously in previous field studies of well-trained sprint kayakers.[10]

2.4. Video Analysis

The crews were recorded from the right-hand side sagittal view using a high-speed digital video camera sampled at 120 Hz (Casio EX-FH 100, Casio, Shibuya, Tokyo, Japan). The camera was operated by a researcher on a power boat accompanying alongside the K2 crew from about 9 m away. No calibration was necessary as the variables of interests were temporal variables on timings. In order to view the paddle blade positions of both K2 members concurrently, sagittal view recordings were the most suitable as other views (e.g. frontal or dorsal) could have the paddle blades obstructed. This method of sagittal view recordings had been used in other studies on crew boat kayaking.[7,8]

Video analyses of stroke synchronization within each K2 crew were performed in the open source freeware Kinovea (Version 0.8.15, Joan Charmant & contributors). Performance time was measured based on the tip of the kayak in relation to pair of adjoining buoy markers demarcating the distance. Only the last 200-m section of each 300-m trial was selected for data analysis in order to capture the crews at steady state paddling, and to reduce variability due to reaction time or the initial acceleration.

Stroke synchronization was identified from a four-position stroke model based on the contact area of the paddle blade relative to the water (Figure 1).[7] "Catch" occurred at the first contact between the paddle blade and water. "Immersion" occurred when the blade was maximally submerged. "Extraction" was the last instance where the blade was maximally submerged. "Release" was the last contact between the blade and water. These four positions (catch, immersion, extraction and release) separate the stroke into water phase and aerial phase. In sprint kayaking terminology, a complete stroke cycle beginning and ending on one side (e.g. from right catch to the next right catch) is commonly considered as two strokes.[11]

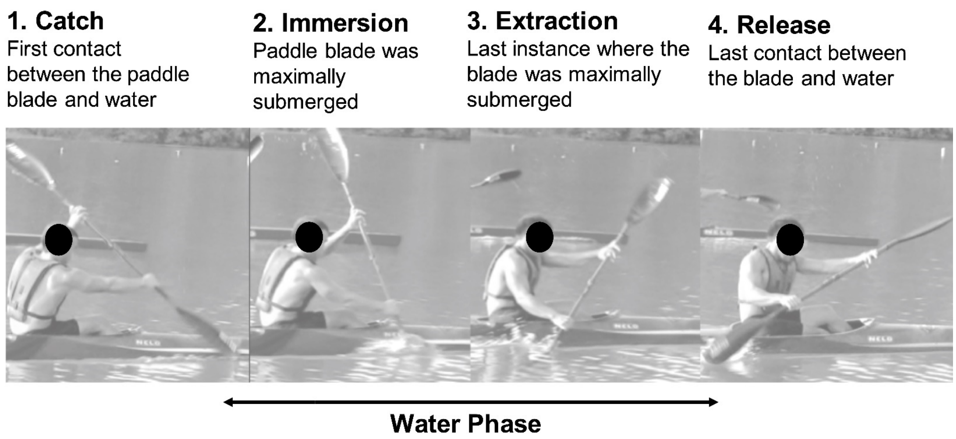

Figure 1: A four-position stroke model (catch, immersion, extraction, release) based on the contact area of the paddle blade relative to the water.

To quantify stroke synchronization within a K2 crew, an offset variable was defined as the timing difference of the back paddler with reference to the front paddler.[7] The offset variable presented here was named as the "difference" in a performance matrix analysis of a four-seater rowing boat, where each rower was compared with reference to the first seat rower.[12] Thus, the offset may be calculated as: Offset (milliseconds) = Timing of back paddler - Timing of front paddler. The offset was measured for each of the four phase-defining positions (catch, immersion, extraction and release) for every right stroke of both paddlers, beginning from the first right stroke after the first 100-m section. With reference to the front paddler, the offset of the back paddler could be negative, zero or positive. An example of a negative offset is when the back paddler catches before the front paddler. The offset was zero if both paddlers reached the same position at the same time. This method of quantifying stroke synchronization in K2 crew boats has been shown to be reliable.[7]

2.5. Statistical Analysis

Given the relatively small number of kayakers available in the national team, inferential statistics were not performed. Magnitude-based inference has been recommended for use in sport science research of high-level athletes, as the traditional method of significance testing and *p* values may render meaningful effects insignificant due to the small sample size.[13,14] We chose the magnitude-based inference with 90% confidence limits were used to assess group mean differences, assuming a non-normal distribution as the sample size was eight crews. Calculations were made with a one-group repeated measures spreadsheet calculator (sportsci.org/2006/wghcontrial.htm) to infer the likelihood and magnitude of the effect.

In magnitude-based inference, an effect is first determined to be *substantial* or *trivial* based on the smallest worthwhile change for the outcome. The smallest worthwhile change was determined to be 1.14% (3.8% ×0.3), based on the formula of 0.3 times of the within-athlete variability.[15] Previously, the within-athlete variation was found to be 3.8% for B final men's canoe single 200-m at the major international sprint kayaking competitions from 2003 to 2007.[16] Athletes ranked 9^{th} to 16^{th} after the semi-finals qualify for the B Final. The 3.8% value was the highest within-athlete variability compared to other events and distances such as men's kayak single 1000-m. As there were no reference values for K2 crew boats or submaximal paddling, 3.8% was selected as the closest option. Next, the effect is assigned one of seven qualitative descriptors based on its probability of occurrence: < 1%, *almost certainly not*; 1-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*; 75-95%, *likely*; 95-99%, *very likely*; > 99%, *almost certainly*.[13]

3. Results

Table 2 shows the descriptive results of the effects of seat order on K2 200-m submaximal performance time and stroke characteristics. Table 3 compares the stroke synchronization (offset) between the preferred and revised seat orders. For synchronization, the mean offset values were similar across the four stroke positions with no consistent pattern when comparing the preferred and reversed seat orders.

The reversed seat order was faster for four out of eight crews, similar for two crews, and slower for two other crews. To further explore how performance time may be affected by seat order, data were arranged in two ways: (a) preferred and reverse orders based on experimental conditions, and (b) faster and slower trials based on the performance time regardless of order preference. Figure 2a shows a comparison between the preferred and reversed seat order trials, while Figure 2b compares between the slower and faster trials for each crew.

Table 4 summarises the magnitude-based inferences of the group effects of seat order on 200-m time and stroke synchronization. Crews were first compared between the preferred and reversed seat orders for 200-m time and stroke synchronization. Performance time in the preferred seat order was *possibly* faster by a *trivial* amount than in the reversed seat order. Mean stroke offset in the preferred seat order was *possibly* larger by a *trivial* amount than that of the reversed seat. When data were re-arranged based on timing rather than experimental conditions, performance time in the faster trial was *very likely* faster than in the slower trial. There was a *possibly trivial* increase in mean stroke offsets for the faster trial as compared to the slower trial.

Table 2 Stroke characteristics of K2 200-m in preferred and reverse seat orders

Crew	Seat Order	200-m Performance Time (s)	Stroke Rate (strokes per min)	Water phase duration (ms)		
				Front paddler	Back paddler	Mean of both paddlers
1	Preferred	46.4	89	400	406	403
	Reversed	44.8	92	415	368	391
2	Preferred	45.5	93	384	385	385
	Reversed	47.2	84	404	409	407
3	Preferred	46.0	93	399	390	395
	Reversed	46.2	91	380	380	380
4	Preferred	48.5	79	441	452	447
	Reversed	46.1	86	431	393	412
5	Preferred	52.8	85	466	413	440
	Reversed	50.2	87	406	430	418
6	Preferred	51.5	82	464	452	458
	Reversed	50.3	83	447	442	444
7	Preferred	51.9	81	487	410	449
	Reversed	54.1	78	422	473	448
8	Preferred	52.9	82	446	421	433
	Reversed	53.0	85	429	435	432
		Mean	86	426	416	421

Note. ms = milliseconds. Water phase duration = duration of the paddle blade in water (from catch to release). Mean values were calculated as absolute values i.e. no negative values.

Table 3 Stroke synchronization (offset) of K2 200-m between the front and back paddlers in preferred and reversed seat orders

Crew	Seat Order	Catch	Immersion	Extraction	Release	Mean Offset	
		(ms; %)	(ms; %)	(ms; %)	(ms; %)	(ms; %)	Δ (%)
1	Preferred	-11; 2.7	-2; 0.5	5; 1.3	-5; 1.3	12; 3.0	5.0
	Reversed	1; 0.2	-16; 4.2	-50; 12.8	-46; 11.8	31; 8.0	
2	Preferred	-32; 8.3	-36; 9.4	-31; 8.1	-31; 8.0	33; 8.5	3.3
	Reversed	-10; 2.4	-17; 4.3	-39; 9.6	-5; 1.2	21; 5.2	
3	Preferred	16; 4.1	16; 4.0	13; 3.3	7; 1.9	16; 4.0	1.4
	Reversed	18; 4.8	18; 4.8	-11; 2.8	18; 4.6	20; 5.4	
4	Preferred	10; 2.3	-1; 0.3	-15; -3.4	21; 4.7	20; 4.6	0.9
	Reversed	23; 5.6	27; 6.5	15; 3.6	-15; 3.6	23; 5.5	
5	Preferred	17; 3.9	9; 2.0	-32; 7.2	-36; 8.2	35; 8.0	3.2
	Reversed	-25; 6.1	-19: 4.5	0; 0.1	-1; 0.2	20: 4.8	
6	Preferred	-31; 6.9	-37; 8.1	-50; 11.0	-44; 9.6	42; 9.1	3.0
	Reversed	-19; 4.2	-21; 4.7	-27; 6.0	-23; 5.1	27; 6.1	
7	Preferred	31; 6.9	52; 11.6	-47; 10.6	-46; 10.3	45; 9.9	2.0
	Reversed	-15; 3.4	-44; 9.7	30; 6.7	37; 8.2	35; 7.9	
8	Preferred	33; 7.6	52; 11.9	18; 4.2	8; 1.9	32; 7.5	0.0
	Reversed	-20; 4.7	-34; 7.8	-40; 9.3	-15; 3.4	32; 7.5	
	Mean	20; 4.6	25; 5.9	26; 6.3	22; 5.3	28; 6.6	2.4

Note. ms = milliseconds; Mean values were calculated as absolute values i.e. no negative values.

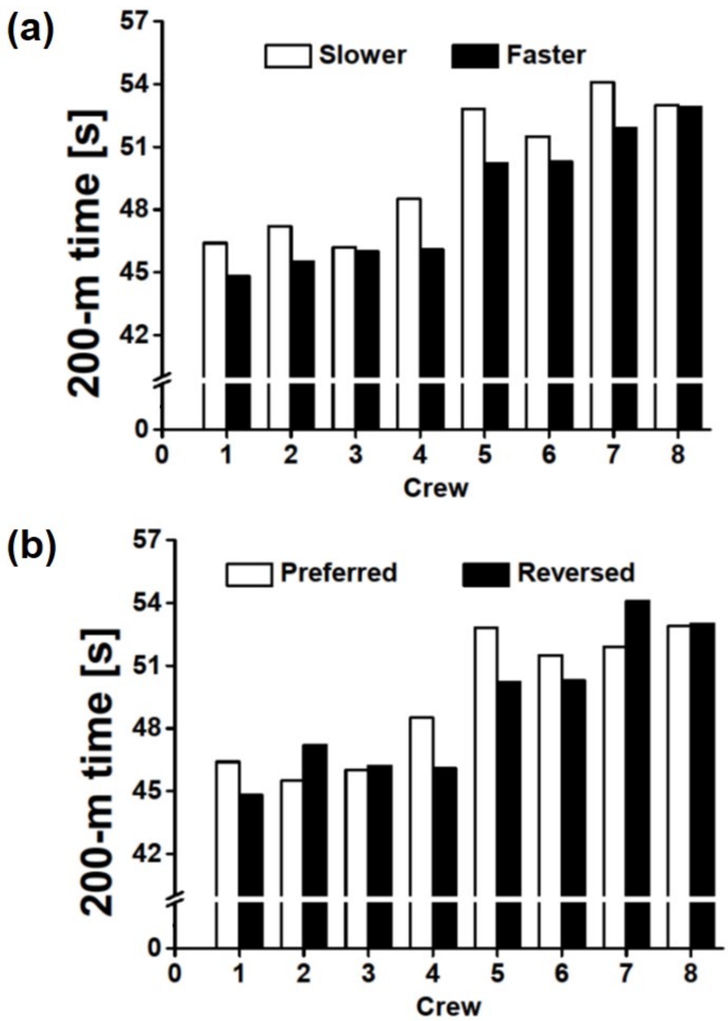

Figure 2: Comparison of 200-m performance time for each K2 crew. Data were arranged in two ways: (a) preferred and reverse seat orders based on experimental conditions, and (b) faster and slower trials based on the performance time regardless of seat order preference.

Table 4 Magnitude-based inferences of the effects of switching seat order on 200-m time and stroke synchronization (offset).

		Mean ± s	MD ± 90% CI	Magnitude-based Inference[a] Harmful/Trivial/Beneficial
(a) Data arranged in preferred versus reversed seat orders				
200-m time (s)	Preferred order	49.4 ± 3.2	-0.5 ± 1.8	8%/49%/43%
	Reversed order	49.0 ± 3.4		Unlikely/Possibly/Possibly
Stroke offset (%)	Preferred order	6.6 ± 2.5	-0.4 ± 2.7	7%/69%/24%
	Reversed order	6.2 ± 1.3		Unlikely/Possibly/Unlikely
(b) Data arranged by slower versus faster trials				
200-m time (s)	Slower trial	50.0 ± 3.2	-1.5 ± 1.0	-/1%/99%
	Faster trial	48.5 ± 3.2		-/Very unlikely/Very likely
Stroke offset (%)	Slower trial	6.2 ± 2.1	0.4 ± 2.7	22%/71%/8%
	Faster trial	6.6 ± 1.8		Unlikely/Possibly/Unlikely

Note. MD ± 90% CL = Mean difference ± 90% confidence interval limits. [a] With reference to a smallest worthwhile change of 1.14%. Data were arranged in two ways: (a) preferred and reverse orders based on experimental conditions, and (b) faster and slower trials based on the performance time regardless of order preference.

4. Discussion

The purpose of the present study was to investigate how seat order of a K2 crew boat could influence performance time and stroke synchronization during high intensity paddling. It was hypothesized that 1) the performance time would be faster in a crew's preferred seat order than a reversed seat order, and 2) stroke synchronization would be more precise in the preferred seat order than the reversed seat order. In the literature, the focus of kayaking research has been primarily on individual one-seater (K1) boat.[17-19] To the authors' best knowledge, this is the first study examining the effect of seat order on stroke characteristics in K2 crew boat. Findings from the present study can add knowledge to the limited body of literature in K2 sprint kayaking.[7,8]

4.1. Performance Time

Contrary to the first hypothesis, the preferred seat order only had a *possibly trivial* effect of being faster than the reversed seat order. It was rather surprising that four out of eight national level crews were faster in the reversed seat order. In a previous case study of a rowing crew, Hill[20] found that performance worsened in a new seat order as compared to the usual seat order. Thus, it was hypothesised that performance would worsen in the non-preferred (reversed) seat order for the sprint kayak crews in this study, but the results showed otherwise. Nonetheless, it could be due to unfamiliarity of the crews with each other, as it was the first crew boat session of the season and they had not paddled in crew boats for six months.

When crews were compared between the faster and slower trials, it was clear that there was a *very likely* difference between the performance time. In other words, there is a correct seat order for faster performance, but this correct seat order is not always the preferred seat order chosen by the athletes. One additional observation was that the faster performance trial for each crew was associated with a higher stroke rate than the slower trial. In the sprint kayaking literature, a higher stroke rate has been linked to successful K1 performance.[21,22] It is thus plausible that a higher stroke rate is also linked to successful crew boat sprint kayaking performance, however, further investigations are needed to test this hypothesis.

At present, the small sample size restricted any robust conclusions on how seat order should be decided. Even with the national level athletes in this study, half of the total number of crews chose incorrectly whereby their preferred seat order turned out to be slower than the reversed seat order. Thus, it is recommended that athletes trying out in a new K2 crew paddle in both their preferred and reversed seat order.

4.2. Stroke Synchronization

The second hypothesis of more precise synchronization in the preferred seat order was not supported as stroke offsets were only marginally higher (*possibly trivial effect*) in the preferred seat order as compared to the reversed seat order. This finding was in line with a recent observation study on sub-elite K2 sprint kayaking crews that found no specific synchronization profiles between the front and back paddlers at the catch, immersion, extraction, or release.[7] In an earlier study on sprint kayaking, it has been proposed that well-synchronized strokes are important for successful crew boat performance.[3] It is possible that both preferred and revised seat orders allowed sufficient stroke synchronization as the paddlers were well-trained and competing at the national level.

As a group, mean synchronization offsets were marginally higher in the faster trial as compared to the slower trial, but there was also much variation among the eight crews studied. Considering that the differences in performance time were *very likely substantial* while the differences in stroke synchronization were *possibly trivial*, it appears that the well-synchronized strokes may not be important for successful crew boat performance. It should be noted, however, that video analysis of stroke timing offsets might not show the full picture of crew boat stroke synchronization. In elite rowing, timing comparisons at the catch and release positions differed by up to 3.1% only, but force profiles were found to differ by as much as 7.7%.[17] The disparity suggests that synchronization in timing and force may have different effects on performance time. Thus, it is recommended that future investigations may consider the use of instrumented paddle systems to perform kinetic stroke measurements in crew boat sprint kayaking.

4.3. Limitations

First, the testing orders were systematically set as the preferred seat order followed by the reversed seat order and not randomized counter-balanced. This was to reflect the actual practice that athletes would try their preferred seat order first before considering the alternative. If athletes were asked to perform the reverse order first, they will likely hesitate and not willing to paddle with good effort. On one hand, performance in the reversed seat order might have been better due to more familiarity of the crew with each other's stroke technique and style. Yet on the other, fatigue may have worsened performance in the reversed order. Future studies should ideally adopt a randomized counter-balanced design of preferred versus reversed seat orders, although it remains challenging to ensure athletes' motivation is high in both conditions. Another limitation of the present study was that maximal intensity paddling was not performed. Instead, the trial protocol was high-intensity paddling based on the individual participant's rating of 15 to 16 on the Borg 6-20 scale. While it would be more relevant for performance if the trials were performed at maximal intensity, it would not be realistic in reflecting the actual practice of two athletes trying out in a K2 for the first time in a competitive season. At all times, it is necessary for the athletes to maintain their balance in the K2 which may be as narrow as 0.31 m at the waterline beam.[23] Thus, even if the prescribed protocol was maximal intensity paddling, athletes might hold back if they feel that the boat was about to roll over and capsize. Future studies could consider a more rigorous approach to monitor paddling intensity such as taking heart rate measurements.

5. Conclusions

This study applied biomechanical engineering technique to address a biological problem of crew boat kayaking in the context of sport. The study findings suggested that seat order in a K2 crew boat has little effect on stroke synchronization during high intensity sprint kayaking. In well-trained sprint kayak athletes, the seat order chosen by the paddlers was not always the best choice as four out of eight crews was faster in the reversed seat order when compared to their preferred order. When the slower and faster trials were compared for each crew, there was a *very likely* (99%) chance that there was a correct seat order leading to faster K2 performance. Since faster timing does not always correspond with the paddlers' preference, sprint kayak athletes are recommended to try both possible seat orders in a K2 boat.

Acknowledgements

Dr Cheryl Tay was supported by the Nanyang President's Graduate Scholarship, Nanyang Technological University.

Disclosure statement

There are no potential conflicts of interest.

References

1. Ong KB, Ackland TR, Hume PA, Ridge B, Broad E, & Kerr DA. Kayak: Equipment set-up among Olympic sprint and slalom kayak paddlers. Sports Biomech 2005;4(1):47-58.
2. Endicott WT. The Barton Mold: A study in Sprint Kayaking. Charlotte, 2005;NC:US Canoe / Kayak.
3. Tellez JC, Hernandez JL S, Imaz X. Tactics, techniques and team selection for K4 boats. In Real Federacion Espanola de Pirguismo (Ed.), Training Sprint Canoeing (pp. 227-251). 2015;Spain: Real Federacion Espanola de Pirguismo.
4. McBride M, Sanderson D, & Elliott B. Seat specific technique in pair oared rowing. In J. R. Bradwell, & R. H. Sanders (Eds.), Proceedings of the XIX International Conference on Biomechanics in Sports (pp. 263-266). 2001;San Francisco, USA.
5. Ritchie AC, & Selamat MF. Comparison of blade designs in paddle sports. Sports Technology 2010;3(2):141-149.
6. Zandi S, Rajabi R, & Tavanaei AR. Are gender, position in boat and training load associated with the injuries in elite dragon boat paddlers? World Journal of Sport Sciences 2010;3(2):113-118.
7. Tay CS, & Kong PW. A video-based method to quantify stroke synchronisation in crew boat sprint kayaking. Journal of Human Kinetics 2018;65:45-56.
8. Robinson MG, Holt LE, Pelham TW, & Furneaux K. Accelerometry measurements of sprint kayaks: The coaches' new tool. International Journal of Coaching Science 2011;5(1):45-56.

9. Borg GA. Psychophysical bases of perceived exertion. Med Science Sports Exerc 1982;14(5):377-381.
10. Place N, & Billat V. New field test to track changes of flatwater paddling performance: A preliminary study. Perceptual and Motor Skills 2012;115(3):933-936.
11. Szanto C. Chapter 7 - The interrelated principles of kayaking and canoeing. ICF Coaches Education Programme Canoe Sprint Coaching Manual Level 2 and 3 (pp. 39-48). 2010;Lausanne: International Canoe Federation.
12. Gravenhorst F, Muaremi A, Draper C, Galloway M, & Tröster G. Identifying unique biomechanical fingerprints for rowers and correlations with boat speed-a data-driven approach for rowing performance analysis. International Journal of Computer Science in Sport 2015;14(1):4-33.
13. Hopkins WG. Probabilities of clinical or practical significance. Sportscience 2002;6. sportsci.org/jour/0201/wghprob.htm
14. Batterham AM, & Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 2006;1(1):50-57.
15. Hopkins WG, Hawley JA, & Burke LM. Design and analysis of research on sport performance enhancement. Med Sci Sports Exerc 1999;31(3):472-485.
16. Bonetti DL, & Hopkins WG. Variation in performance times of elite flat-water canoeists from race to race. Int J Sports Physiol Perform 2010;5(2):210-217.
17. Gomes BB, Machado L, Ramos NV, Conceição FAV, Sanders RH, Vaz MAP, Vilas-Boas JP, Pendergast DR. Effect of wetted surface area on friction, pressure, wave and total drag of a kayak. Sports Biomech 2018;17(4):453-461.
18. Hamacher D, Krebs T, Meyer G, Zech A. Does local dynamic stability of kayak paddling technique affect the sports performance? A pilot study. Eur J Sport Sci. 2018;18(4):491-496.
19. Bjerkefors A, Rosén JS, Tarassova O, Arndt A. Three-dimensional kinematics and power output in elite para-kayakers and elite able-bodied flat-water kayakers. J Appl Biomech. 2019;35(2):93-100.
20. Hill H Dynamics of coordination within elite rowing crews: Evidence from force pattern analysis. J Sports Sci 2002;20(2):101-117.
21. McDonnell LK, Hume PA, & Nolte V. A deterministic model based on evidence for the association between kinematic variables and sprint kayak performance. Sports Biomech 2013;12(3):205-220.
22. McDonnell LK, Hume PA, & Nolte V. Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition. Int J Perform Analy Sport 2013;13(1):38-50.
23. Elliott C. Basic hydrostatic test. In B., Grail, M. Bohm, A., Hunter, & C., Elliott (Eds). "The Big Kayak Test" Results (p. 127). 2006;Victoria: Australia.